87-316

87-316

No. _____

Supreme Court, U.S.
FILED
JUL 20 1987
JOSEPH F. SPANIOL, JR.
CLERK

In The

Supreme Court of the United States

October Term, 1987

IRENE H. ALLEN, et al.,

Petitioners,

v.

UNITED STATES OF AMERICA,

Respondent.

PETITION FOR A WRIT OF CERTIORARI TO THE UNITED STATES COURT OF APPEALS FOR THE TENTH CIRCUIT

APPENDIX TO PETITION

D. DALE HARALSON
Counsel of Record
DENNEEN L. PETERSON
HARALSON, KINERK & MOREY, P.C.
82 South Stone Avenue
Tucson, Arizona 85701
(602) 792-4330

RALPH HUNSAKER
DAVID M. BELL
SCOTT E. BOEHM
O'CONNOR, CAVANAGH, ANDERSON
WESTOVER, KILLINGSWORTH &
BESHEARS
One East Camelback, Suite 1100
Phoenix, Arizona 85012
(602) 263-2604

STEWART K. UDALL
Attorney At Law
70 East Mitchell
Phoenix, Arizona 85012
(602) 230-1254

J. MacARTHUR WRIGHT
WRIGHT & MILES
60 North 300 East
P.O. Box 339
St. George, Utah 84770
(801) 623-2612

47 5 1P

EDITOR'S NOTE

THE FOLLOWING PAGES WERE POOR HARD COPY AT THE TIME OF FILMING. IF AND WHEN A BETTER COPY CAN BE OBTAINED, A NEW FICHE WILL BE ISSUED.

TABLE OF CONTENTS: APPENDIX*

Opinion of Tenth Circuit Court of Appeals, filed April 20, 1987 . . . . . .A

Opinion of the Federal District Court, filed May 10, 1984. . . . . .B

Opinion of the Federal District Court, filed August 21, 1981 C

Judgment of Tenth Circuit Court of Appeals, filed June 9, 1987 . . . . . .D

Excerpts from the Atomic Energy Act of 1946. . . . . .E

Excerpts from the Atomic Energy Act of 1954. . . . . .F

*Appendices separated by blue pages bearing title of appendix subsection.

APPENDIX A

Opinion of Tenth Circuit Court of Appeals

filed April 20, 1987

PUBLISH

UNITED STATES COURT OF APPEALS

TENTH CIRCUIT

IRENE H. ALLEN, et al.,	)	
	)	
Plaintiffs-Appellees,	)	
	)	
v.	)	No. 84-2126
	)	
UNITED STATES OF AMERICA,	)	
	)	
Defendant-Appellant.	)	

Appeal from the United States District Court
for the District of Utah
(D.C. No. C 79-0515)

Marc Johnston, Appellate Staff Attorney, Civil Division, Department of Justice (Richard K. Willard, Acting Assistant Attorney General; Robert S. Greenspan, Appellate Staff Attorney, Civil Division, Department of Justice; Brent D. Ward, United States Attorney; Henry A. Gill, Acting Assistant General Counsel, and Edward Jiran, Attorney, Department of Energy; Ralph H. Johnson, Pamela L. Wood, and Patrick O. Cavanaugh, Trial Attorneys, Torts Branch, Civil Division, Department of Justice, with him on the brief), Washington D.C. for Defendants-Appellants.

Dale Haralson of Haralson, Kinerk & Morey, Tucson, Arizona, and Ralph E. Hunsaker of O'Connor, Cavanagh, Anderson, Westover, Killingsworth & Beshears, Phoenix, Arizona (Denneen L. Peterson of Haralson, Kinerk & Morey; David M. Bell and Scott E. Boehm of O'Connor, Cavanagh, Anderson, Westover, Killingsworth & Beshears; Stewart L. Udall of Beer and Toone, Phoenix, Arizona; J. MacArthur Wright of Wright & Miles, St. George, Utah, with them on the brief), for Plaintiffs-Appellees.

Before McKAY, SETH, and LOGAN, Circuit Judges.

LOGAN, Circuit Judge.

In this action under the Federal Tort Claims Act, see 28 U.S.C. §§ 1346(b), 2401(b), 2671-80, nearly 1200 named plaintiffs have sued the United States, alleging some 500 deaths and injuries as a result of radioactive fallout from open-air atomic bomb tests held in Nevada in the 1950s and 1960s. The district court selected and tried twenty-four "bellwether" claims, in order to find a common framework for the rest.[1] See Allen v. United States, 588 F. Supp. 247, 258 (D. Utah 1984). The court entered final judgment in favor of the government on fourteen of these claims and against the government on nine, leaving one claim outstanding. Id. at 446-47. It then granted a Fed. R. Civ. P. 54(b) motion permitting the government to appeal those claims resolved against it. On appeal the government contends that (1) the "discretionary function" exception in 28 U.S.C. § 2680(a) precludes government liability; (2) the government did not breach any duty owed to the public; (3) the government did not cause plaintiffs' injuries; and (4) the plaintiffs' claims were barred by the two-year statute of limitations in U.S.C. § 2401(b). We do not discuss the last three issues, because we agree that the discretionary function exception precludes government liability.

The district court opinion states the facts fully. See Allen, 588 F. Supp. at 337-38, 348-50, 358-404. The authority for federal atomic bomb tests came from the Atomic Energy Act of 1946, Pub. L. No. 585, 60 Stat. 755 ("the 1946 Act"). See Atomic Energy Act of 1954, 42 U.S.C. §§ 2011-2296 (present version of atomic energy statutes). Under the 1946 Act, the Atomic Energy Commission (AEC) received broad discretionary power to "conduct experiments . . . in the military application of atomic energy." 1946 Act, § 6(a); see 42 U.S.C. § 2121(a) (same authority in present statutes).[2] The AEC was authorized to carry on such experiments "only to the extent that the express consent and direction of the President of the United States

[1] The trial lasted thirteen weeks. The trial transcript runs more than 7,000 pages; the exhibit evidence more than 54,000 pages. The district court deliberated for seventeen months, then issued an opinion which occupies 225 pages of the Federal Supplement.

[2] In 1974, the AEC was abolished and its functions transferred to the Nuclear Regulatory Commission and the Energy Research and Development Administration. Energy Reorganization Act of 1974, Pub. L. No. 93-438, 88 Stat. 1233.

has been obtained, which consent and direction shall be obtained at least once each year." Id. Additionally, the AEC was "authorized and directed to make arrangements . . . for . . . the protection of health during research and production activities." 1946 Act, § 3(a). These arrangements were to "contain such provisions to protect health, to minimize danger from explosion and other hazards to life or property . . . as [the AEC] may determine." Id.; see 42 U.S.C. §§ 2012(d)-(e), 2013(d), 2051(d) (similar provisions in present statutes).

In 1950 the AEC chose an area in Nevada as a testing site. The President approved this choice. Thereafter, between 1951 and 1962, eight series of open-air tests were conducted, with the President approving each series of tests. Over one hundred atomic bombs were detonated.

Each test explosion was executed according to detailed plans which the AEC officially reviewed and adopted. Separate plans for protecting the public, and for providing the public with appropriate information, were also adopted by the AEC. To actually execute the plans, however, the AEC delegated some of its authority. The AEC selected a "Test Manager" for each test series, who had some day-to-day discretion. The Test Manager could, for example, postpone a given test because of adverse weather conditions. The Test Manager in turn delegated authority to a Radiological Safety Officer (a "Radsafe Officer") who was in charge of implementing plans to avoid radiation dangers, and a Test Information Officer who was in charge of implementing plans to provide public information on the tests. Both the Radsafe Officer and the Test Information Officer also had some day-to-day discretion in performing their duties.

At trial, as a basis for governmental liability, plaintiffs singled out the alleged failure of the government, especially of the Radsafe Officers and the Test Information Officers, to fully monitor offsite fallout exposure and to fully provide needed public information on radioactive fallout. The district court focused on these two failures in finding government liability. Allen, 588 F. Supp. at 372-404.

The Federal Tort Claims Act (FTCA) authorizes suits for damages against the United States

> "for injury or loss of property, or personal injury or death caused by the negligent or wrongful act or omission of any employee of the Government while acting within the scope of his office or employment, under circumstances where the United States, if a private person, would be liable to the claimant in accordance with the law of the place where the act or omission occurred."

28 U.S.C. § 1346(b). In such suits, the United States is liable "in the same manner and to the same extent as a private individual under like circumstances." 28 U.S.C. § 2674. Suit is not allowed, however, for any claim

> "based upon an act or omission of an employee of the Government, exercising due care, in the execution of a statute or regulation, whether or not such statute or regulation be valid, or based upon the exercise or performance or the failure to exercise or perform a discretionary function or duty on the part of a federal agency or an employee of the Government, whether or not the discretion involved be abused."

28 U.S.C. § 2680(a) (emphasis added). The key term, "discretionary function," is not defined. For over thirty-five years the federal courts have been attempting to define it.

Plaintiffs in the present case attempted to distinguish between the discretionary initiation of government programs, at the highest levels of administration, and the decisions involved in carrying out programs, at lower levels. Plaintiffs argued that while low-level decisions may involve some "judgment," they do not fall within the discretionary function exception of § 2680(a). See, e.g., Indian Towing Co. v. United States, 350 U.S. 61, 64 (1955) (reference to "operational level" of activity; no immunity found for government failure to operate lighthouse). The district court agreed, basing its finding of government liability squarely on a distinction between high-level and low-level government activity. Allen, 588 F. Supp. at 335-40.

After the district court judgment in the present case, the Supreme Court decided United States v. S.A. Empresa de Viacao Aerea Rio Grandense (Varig Airlines), 467 U.S. 797 (1984), in which it explicitly rejected distinctions based on the administrative level at which the challenged activity occurred. In Varig, various plaintiffs brought an FTCA suit against the United States, claiming that the Federal Aviation Administration (FAA) had negligently implemented plane inspection and design certification programs, allowing improper flammable materials and a defective heater system to be used to construct a specific Boeing 707 and a specific DeHavilland Dove. The planes in question caught fire and burned, killing most of those on board. The Supreme Court held, however, that the United States was immune from suit. The court found that the contested FAA actions constituted the performance of a "discretionary function," exempt under 28 U.S.C. § 2680(a) from potential FTCA liability. 467 U.S. at 819-21.

The plaintiffs in Varig focused on "low-level" decisions in their suit. They challenged the actual issuance by the FAA of design approval certificates for two plane types, the decision to enforce FAA standards with a particular "spot-check" system, and the actual plane inspections that were and were not carried out under that sytem. 467 U.S. at 799-803, 816-20. The Supreme Court found that each of these actions constituted a discretionary function, immune from suit under § 2680(a):

> " '[T]he "discretionary function or duty" that cannot form a basis for suit under the Tort Claims Act includes more than the initiation of programs and activities. It also includes determinations made by executives or administrators in establishing plans, specifications or schedules of operations. Where there is room for policy judgment and decision there is discretion. It necessarily follows that acts of subordinates in carrying out the operations of government in accordance with official directions cannot be actionable.' "

Id. at 811 (quoting Dalehite v. United States, 346 U.S. 15, 35-36 (1953)). The Court emphasized that it is "the nature of the conduct, rather than the status of the actor, that governs whether the dis-

cretionary function exception applies in a given case." Varig, 467 U.S. at 813.

On appeal, plaintiffs contend that the AEC, in planning and conducting its monitoring and information programs, was not making the kind of policy judgments protected by § 2680(a). They point to the general statutory provisions instructing the AEC to consider public health and safety, and claim that these broad congressional directives leave no further room for discretion. We disagree.

In the case before us, as in Varig, the government actors had a general statutory duty to promote safety; this duty was broad and discretionary. In the case before us it was left to the AEC, as in Varig it was left to the Secretary of Transportation and the FAA, to decide exactly how to protect public safety. If anything, the obligation imposed on the FAA to protect public safety was greater and the discretion granted to the FAA by Congress was less, in the circumstances reviewed by Varig, than the comparable obligation imposed and discretion available to the AEC in the present case. Compare 49 U.S.C. § 1421 (FAA safety duty) with 42 U.S.C. § 2051(d) (AEC safety duty). We cannot say that what was protected by the Supreme Court in Varig is now subject to liability.

Plaintiffs further contend that, even if the initial discretion granted the AEC by statute was broad, test site personnel violated the AEC's own policy directives by failing to implement adequate protective measures. We cannot accept this argument either. Neither the plaintiffs nor the district court have been able to point to a single instance in which test site personnel ignored or failed to implement specific procedures mandated by the AEC for monitoring and informing the public. Indeed, the district court's conclusions appear to be based, at least in part, on perceived inadequacies in the AEC's radiological safety and information plans themselves.[3] The court relied heavily on

[3] The district court stated that its review of "the various radiation safety plans, public information plans, and related documents" disclosed the "astounding fact" that no concerted effort was made "to directly monitor and record internal contamination or dosage in off-site residents on a comprehensive person-specific basis." Allen, 588 F. Supp. at 373-74.

a 1954 report to the AEC by the Committee to Study Nevada Proving Grounds which was moderately critical of the measures taken up to that point to inform and warn the public. See Allen, 588 F. Supp. at 386-90, 392-93. The stated objective of this report, however, was "[t]o be a basis for Commission decisions on future policy." Pl. Ex. at 4. The operational plans the district court considered deficient embody those AEC policy decisions. As such, these plans clearly fall within the discretionary function exception.[4]

Government liability cannot logically be predicated on the failure of test-site personnel to go beyond what the operational plans specifically required them to do. If, as the plaintiffs maintain, the AEC delegated "unfettered authority" to a Test Manager and his subordinates to implement public safety programs, this simply compels the conclusion that those officers exercised considerable discretion. Their actions, accordingly, also fall within the discretionary function exception.

It is irrelevant to the discretion issue whether the AEC or its employees were negligent in failing to adequately protect the public. See Cisco v. United States, 768 F.2d 788, 789 (7th Cir. 1985); General Public Utilities Corp., 745 F.2d 239, 243, 245 (3d Cir. 1984), cert. denied, 469 U.S. 1228 (1985).[5] When the conduct at issue involves the exercise of discretion by a government agency or employee, § 2680(a) preserves governmental immunity "whether or

---

[4] In the one instance which suggested that a subordinate contradicted an official direction by a superior, the district court quoted at length from a document which it characterized as a modification or redetermination of AEC policy regarding off-site exposure levels by personnel at the "NTS operational level." Allen, 588 F. Supp. at 385-86. But the district court was actually quoting from the official Operations Plan for the RANGER test series which had been annexed as an appendix to the Rad-Safe Group's after-series report. Def. Ex. 88 at 66, 69.

[5] It is also irrelevant whether the alleged failure to warn was a matter of "deliberate choice," or a mere oversight. See Allen, 588 F. Supp. at 337-38. We agree with the treatment of this distinction in Myslakowski v. United States, 806 F.2d 94 (6th Cir. 1986), cert. denied, _____ U.S. _____ (1987):

> "The critical error in the trial court's analysis is in its conclusion that because the evidence does not show that the departmental policymakers evaluated the pros and cons of requiring that a warning be given concerning

not the discretion involved be abused." For better or worse, plaintiffs here "obtain their 'right to sue from Congress [and] necessarily must take it subject to such restrictions as have been imposed.' " Dalehite v. United States, 346 U.S. 15, 31 (1953) (quoting Federal Housing Administration v. Burr, 309 U.S. 242, 251 (1940)).[6]

To be sure, the circumstances in Varig are not identical to those now before us. Most notably, Varig involved the actions of a regulatory agency supervising private individuals. The Court observed in Varig that the discretionary actions of government regulators were at the core of what § 2680(a) was intended to protect. But Varig expressly reaffirmed the earlier Supreme Court decision of Dalehite v. United States, 346 U.S. 15 (1953), which found very broad governmental immunity outside a regulatory setting. See Varig, 467 U.S. at 810-14.

---

the rollover propensity of the jeep and then made a discretionary decision not to give such warnings, it therefore follows that no discretionary decision, of the kind contemplated by § 2680(a), was made . . . .

Stated otherwise, even the negligent failure of a discretionary government policymaker to consider all relevant aspects of a subject matter under consideration does not vitiate the discretionary character of the decision that is made.

Indeed, it is, in part, to provide immunity against liability for the consequences of negligent failure to consider the relevant, even critical, matters in discretionary decisionmaking that the statutory exception exists. If it were otherwise, a judgment-based policy determination made at the highest levels, to which all would concede that the statutory exception applies (the decision to sell surplus jeeps), would result in no immunity if the decision could be shown to have been made without consideration of important, relevant factors, or was a decision negligently reached. If that reasoning were sound, the discretionary function exception would be inapplicable in every case in which a negligent 'failure to consider' a relevant risk could be proved."

Id. at 97-98. Accord In re Consolidated United States Atmospheric Testing Litigation, 616 F. Supp. 759, 776-77 (N.D. Cal.), appeal docketed, No. 85-2842 (9th Cir. 1985).

[6] Plaintiffs rely heavily upon an AEC policy report accepting responsibility for reimbursing radiation-caused losses. We cannot treat such an agency statement as waiving the "discretionary function" exclusion Congress placed in the FTCA. The existence of an adminstrative claims system does not constitute a waiver of sovereign immunity. See United States v. Shearer, 473 U.S. 52, _____, 105 S. Ct. 3039, 3043 n.4 (1985); Feres v. United States, 340 U.S. 135, 144-45 (1950).

In Dalehite, private plaintiffs sued the government over deaths, injuries, and property damage resulting from a disastrous explosion of two shiploads of ammonium nitrate fertilizer. 346 U.S. at 22-23. As with the AEC bomb-testing program before us here, Congress and the President, in response to international tensions following World War II, had decided on a crash government program—in Dalehite, a program to feed the populations of Korea, Japan, and Germany. Id. at 19-20. Broad general authority was given to the War Department, and the War Department created a plan for massive fertilizer shipments. The Army's Chief of Ordnance was delegated discretionary responsibilities for carrying out the War Department plan, and he in turn appointed a "Field Director of Ammunition Plants" to administer the program. Id. Other lower-level plant managers and supply officers were also appointed.

As with the AEC bomb tests, the production of fertilizer in Dalehite involved a mix of private and public facilities and employees. Id. at 20-21. As with the AEC bomb tests, all plans for manufacture, packing, and shipping of the fertilizer in Dalehite were officially approved. Id. at 38-40. The Dalehite plaintiffs, like the present plaintiffs, were unable to point to any instances in which government employees acted negligently in performing specific, mandatory duties. The Dalehite plaintiffs instead argued primarily, just as the present plaintiffs argue here, that at various points the government could have made better plans, and that the government failed to fully investigate the hazards of the dangerous material involved and to fully inform and warn the nearby populace. Id. at 23.

The Supreme Court in Dalehite found every contested government decision, action, and omission to be the performance of a discretionary function, exempt from suit under § 2680(a): the cabinet-level decision to export the fertilizer, the lower-level failure to fully test for explosive properties, the Field Director's fertilizer production plan, the actual production of the fertilizer in accordance with the government specifications, and the specific decisions to bag the fertilizer at a certain temperature and to label the fertilizer in a certain way. Id. at 24, 36-42. The various actions and omissions of the Coast Guard, supervising the actual loading of the ships, were also exempted, as

was the general failure to warn the nearby populace of potential dangers. Id. at 23-24, 43.[7]

In Varig, The Supreme Court approved the view of § 2680(a) expressed in Dalehite, strongly rejecting any suggestion that later cases had narrowed the broad immunity found there. Varig, 467 U.S. at 810-14. Given the Court's holding in Dalehite, reaffirmed in Varig, we must conclude that the government is immune from liability for the failure of the AEC administrators and employees to monitor radioactivity more extensively or to warn the public more fully than they did.[8]

---

[7] The Court in Dalehite approved a series of earlier lower court interpretations of § 2680(a), which the Court stated were generally "in conformity with our holding." Dalehite, 346 U.S. at 36 n. 32. The cited cases demonstrate the Court's intent in Dalehite to include extremely low-level and mundane decisions and implementations of decisions within the discretionary function exception of § 2680(a). See, e.g., Toledo v. United States, 95 F. Supp. 838, 839, 841 (D.P.R. 1951) (suit over car damage caused by tree at government facility falling on car; court holds that § 2680(a) bars recovery for failure to remove diseased experimental tree, but notes that negligent removal of tree might not be exempt); Olson v. United States, 93 F. Supp. 150, 152-53 (D.N.D. 1950) (suit for property damage caused by questionable discretionary decision of government employees to release flood waters from dam; court holds that § 2680(a) bars recovery).

[8] We have previously followed the command of the Supreme Court in Varig. See Russell v. United States, 763 F.2d 786, 787 (10th Cir. 1985) (no government FTCA liability possible, for failure of federal mine inspectors to more fully inspect Utah coal mine). Most of the post-Varig decisions of the other circuits are in accord with our holding today. See, e.g., Myslakowski v. United States, 806 F.2d 94, 97-99 (6th Cir. 1986) (no liability for Postal Service decision to sell used jeeps, without warning buyers of jeep propensity to tip over), cert.denied, _____ U.S. _____ (1987); Ford v. American Motors Corp., 770 F.2d 465, 466-68 § 5th Cir. 1985) (same); Smith v. Johns-Manville Corp., 795 F.2d 301, 306-09 (3d Cir. 1986) (no liability for GSA decision to sell asbestos without warning of hazards); Merklin v. United States, 788 F.2d 172, 174-75 (3d Cir. 1986) (no liability for AEC inspectors' failure to warn uranium processing plant employees of health hazards discovered during AEC inspections); Ostera v. United States, 769 F.2d 716, 718 (11th Cir. 1985) (no liability for FBI decision to obtain release of particular person from prison to use as informant); Begay v. United States, 768 F.2d 1059, 1066 (9th Cir. 1985) (no liability for U.S. Public Health Service failure to warn uranium miners of radiation hazards); Cisco v. United States, 768 F.2d 788, 789-90 (7th Cir. 1985) (no liability for EPA failure to warn residents of landfill dirt contaminated with dioxin);

In the instant case, no evidence was presented of any act or omission of the AEC or its employees that clearly contravened a specific statutory or regulatory duty, or that exceeded statutory or regulatory authority. There was no evidence, for example, that the Test Information Officer failed to release information he was required to give out, or that the Radsafe Officer failed to take a specific radiation measurement that had been decided upon. Plaintiffs' entire case rests on the fact that the government could have made better plans. This is probably correct, but it is insufficient for FTCA liability.

Our decision here adheres to the principle enunciated by the Supreme Court of broad sovereign immunity. An inevitable consequence of that sovereign immunity is that the United States may escape legal responsibility for injuries that would be compensible if caused by a private party. There remain administrative and legislative remedies; we note the express authorization under 42 U.S.C. § 2012(i) for the government to make funds available for damages suffered by the public from nuclear incidents. Nonetheless, judicial reluctance to

---

Baxley v. United States, 767 F.2d 1095, 1097-98 (4th Cir. 1985) (no liability for FAA failure to regulate "ultralight" aircraft); Shuman v. United States, 765 F.2d 283, 291 (1st Cir. 1985) (no liability for Navy failure to warn shipyard workers of asbestos hazards); Hylin v. United States, 755 F.2d 551, 554 (7th Cir. 1985) (no liability for federal mine inspectors' failure to fully inspect clay mine); Feyers v. United States, 749 F.2d 1222, 1227 (6th Cir. 1984) (no liability for Army's failure to inspect Chrysler's operation of government-owned railyard), cert. denied, 471 U.S. 1125 (1985); General Public Utilities Corp. v. United States, 745 F.2d 239, 247 (3d Cir. 1984) (no liability for Nuclear Regulatory Commission's failure to warn of possible equipment defects at the Three Mile Island nuclear facility), cert. denied, 469 U.S. 1228 (1985); Flammia v. United States, 739 F.2d 202, 204 (5th Cir. 1984) (no liability for INS's "specific operational decision" to permit a Cuban refugee known to be a convicted felon to enter the United States). But see Aslakson v. United States, 790 F.2d 688, 691-94 (8th Cir. 1986) (FTCA liability possible for government agency's failure to comply with its own already established safety policy); Henderson v. United States, 784 F.2d 942, 943 n.2 (9th Cir. 1986) (FTCA liability possible, for government missile facility safety decision not made "at the planning stage," but "operational in nature"); Collins v. United States, 783 F.2d 1225, 1228-31 (5th Cir. 1986) (FTCA liability possible, for failure of Mine Safety and Health Administration to close mine, when challenged decisions of subordinates did not involve "policy" decisions, or involved only explicit mandatory duties); Alabama Electric Cooperative v. United States, 769 F.2d 1523, 1526-29 (11th Cir. 1985) (FTCA liability possible, for "operational" decisions of Army Corps of Engineers in constructing river dikes).

recognize the sometimes harsh principle of sovereign immunity explains much of the tangle of the prior FTCA cases.

The Court stated in Varig that the purpose of § 2680(a) was to avoid any judicial intervention that "would require the courts to 'second-guess' the political, social, and economic judgments of an agency." 467 U.S. at 814. The bomb-testing decisions made by the President, the AEC, and all those to whom they were authorized to delegate authority in the 1950s and 1960s, were among the most significant and controversial choices made during that period. The government deliberations prior to these decisions expressly balanced public safety against what was felt to be a national necessity, in light of national and international security. However erroneous or misguided these deliberations may seem today, it is not the place of the judicial branch to now question them.

For the above reasons, we find all challenged actions surrounding the government atomic bomb tests in the 1950s and 1960s to be immune from suit, as the performance by a federal agency of a "discretionary function," protected by § 2680(a).

We REVERSE the district court's decision with regard to those nine claims in which the government was found to have liability and REMAND for further proceedings consistent with this opinion.

(THIS PAGE LEFT BLANK INTENTIONALLY)

No. 84-2126 — IRENE H. ALLEN, et al. v. UNITED STATES OF AMERICA. McKAY, Circuit Judge, concurring:

It undoubtedly will come as a surprise to many that two hundred years after we threw out King George III, the rule that "the king can do no wrong" still prevails at the federal level in all but the most trivial of matters. After the passage of the Federal Tort Claims Act, 28 U.S.C. §§ 2671-2680 (1982) (FTCA), many people, as well as the lower federal courts, assumed that the old governmental immunity from responsibility for negligent conduct that injures individual citizens was gone. Many endorsed what appeared to be the FTCA's policy that if the citizens at large benefited from a government program, that collective citizenry, not the isolated individual injured by the negligent conduct of the program, would bear the economic burden of that injury. This case dramatically illustrates that, as interpreted by the Supreme Court in United States v. S.A. Empresa de Viacao Aerea Rio Grandense (Varig Airlines), 467 U.S. 797 (1984), the FTCA (and for that matter Congress's injunction that a program be carried out safely) is largely a false promise in all but "fender benders" and perhaps some cases involving medical malpractice by government doctors.

When Congress decided to employ above-ground testing, it repeatedly evinced the general intent that the tests should be conducted so as not to jeopardize the health and safety of the population downwind.[1] However, it did not delineate the health and safety measures to be taken. No mention is made of how fallout from open-air testings should be monitored or how the public should be educated regarding the effects of fallout—the two issues litigated in this case. The responsibility for developing defined health and safety plans and for disseminating information was instead delegated to the AEC.

Based on ample evidence, the trial court found that the people who designed the downwind safety program deviated from optimum practices based on the best available scientific knowledge. On a fully

---

[1] See The Atomic Energy Act of 1946, ch. 724, 60 Stat. 755 and The Atomic Energy Act of 1954, ch. 1073, 68 Stat. 921 (codified as amended at 42 U.S.C. §§ 2011-2296 (1982 & Supp. III 1985)). For detailed discussion of the two act's safety provisions, see Allen v. United States, 588 F. Supp. 247, 348-50 (D. Utah 1984).

supported record, the trial court found the following deviations in the plans which would clearly support liability for injury under standard tort analysis as applied by the trial court: the decision to monitor randomly rather than on a "comprehensive, person-specific basis," Allen v. United States, 588 F. Supp. 247, 374 (D. Utah 1984); decisions not to use thyroid or whole body counters, id. at 375; decisions regarding the limited extent of urine, fecal, and blood sampling, id. at 374; the decision not to test milk samples "in order to avoid arousing public concern," id. at 375; the decisions to forego internal fallout assessment from inhalation of fallout particles, id. at 376; decisions regarding the extent of follow-up monitoring in downwind communities, id. at 379; the decision to distribute film badges and pocket dosimeters to a select number of residents rather than to every resident, id. at 379-81, 384-85; the decisions regarding duration of monitoring, id. at 381; the decisions with respect to the quantum of personnel and equipment committed to the monitoring program, id. at 381-82; and the decisions concerning the content and appropriate tone of the information given the public as well as the decisions to use pamphlets and films as the education media, id. at 385-404.

Again, on a fully supported record, the trial court found that these departures from accepted safety standards were the proximate cause of suffering and death from cancer in many of the plaintiffs. Under the then-available legal precedents, the trial court reasonably concluded that the FTCA showed Congress's intent that the Government, which benefited from the testing, should bear these particular costs. The critical analysis dealt with Congress' decision in the FTCA to exempt from liability those government acts broadly and vaguely described as "discretionary functions." See 28 U.S.C. § 2680(a).

At the time of the trial court's decision, the leading construction of that provision by the Supreme Court was Dalehite v. United States, 346 U.S. 15 (1953). Language in Dalehite invited some courts to focus on the bureaucratic level of the decision maker in determining whether the ensuing decision or action was clothed with immunity under the discretionary function exception. Cabinet-level actions were considered clearly of a "planning" nature and thus immune. A vehicular collision resulting from driver negligence involved "operational" action and was not immune. See Dalehite, 346 U.S. at 28.

37. Struggling to give meaning to the elusive terms "discretionary function," and noting particularly the subsequent decisions of the Supreme Court in Rayonier Inc. v. United States, 352 U.S. 315 (1957), and Indian Towing Co. v. United States, 350 U.S. 61 (1955), some courts thought the Supreme Court intended to narrow the sweep of its Dalehite interpretation of that exception. See, e.g., Relf v. United States, 433 F. Supp. 423, 427 (D.D.C. 1977), aff'd, 593 F.2d 1371 (D.C. Cir. 1979). Following that pattern, the trial court in this case focused on the decisions made at the operational level. It concluded they were not immune.

Since the appeal was lodged in this case, the Supreme Court decided Varig Airlines. That opinion removed all doubt as to whether the discretionary function exception is to be construed broadly or narrowly. In Varig the Court explicitly denounced both the increasingly narrow construction given the exception since Dalehite and the interpretation of Dalehite that focused on the bureaucratic level of the decision maker. The Court stated, "[I]t is the nature of the conduct, rather than the status of the actor, that governs whether the discretionary function applies in a given case." Varig Airlines, 467 U.S. at 813. It breathed vitality into Dalehite by selectively quoting language other than the planning/operational language most often cited previously: "Where there is room for policy judgment and decision there is discretion." Id. at 811 (quoting Dalehite, 346 U.S. at 36). The Court thus shifted the discretionary function inquiry back toward examining the nature and character of the governmental action to determine whether it is of the type intended to be protected from tort liability by Congress. Those decisions "grounded in social, economic, and political policy," id. at 814, are insulated from our review, regardless of who the decision maker happens to be or how negligent the decision or action may be.

The majority opinion fully deals with the Supreme Court's focus in Varig Airlines. It is sufficient here to note that the focus is on the nature of the planning or decision making rather than on the level at which that planning or its implementation takes place. While that may create analytical problems even in automobile accident cases where the driver is left to "plan" how to drive and carry out his mission in the most economic fashion, both the facts and language of

Varig easily cover the facts of this case. Varig involved an allegedly faulty safety inspection program for aircraft. The factual parallel to the safety programs at issue here cannot be distinguished on a principled basis. Varig Airlines gives little help to lower courts applying the new standard to specific facts—if the FTCA waiver of immunity indeed applies to anything but trivial government failures, such as automobile accidents. Nonetheless, it removes all doubt that the discretionary function exception swallows the negligent decisions before us.

The AEC devised safety and information plans prior to every open-air detonation, tailoring the plans to the demands of each specific project. None of the trial court's documented list of failures represents an instance of deviation from, or negligent implementation of, the safety and information plans adopted.[2] Rather, the court's extensive criticisms and ultimate conclusions of negligence were directed at the substance and failures of the plans themselves.

On appeal, plaintiffs do assert that "the evidence clearly demonstrates negligent and wrongful failure to execute and deviation from . . . the plans approved by the Commission." Brief for the Appellee at 22 (emphasis in original). However, the evidence does not support this allegation. Not one example is given of a failure to monitor or distribute information as prescribed in the plans.[3] Rather, plaintiff's

---

[2] If the evidence had demonstrated such deviation or negligent implementation, neither Varig Airlines nor Dalehite would bar our review. Both those cases confirm that conformity to a discretionary plan insulates the governmental action from review. See Dalehite, 346 U.S. at 36 ("It necessarily follows that acts of subordinates in carrying out the operations of government in accordance with official directions cannot be actionable."); Varig Airlines, 467 U.S. at 820 (acts of FAA employees immune from review because dictated by immune policy-based program). Deviation from an immune plan or negligent implementation of an immune plan, however, can strip the action of the discretionary function exception, for such governmental action does not involve the type of social, economic, or political policy considerations at the core of the exception.

[3] At one point in their brief, plaintiffs state that the test manager "authorized [the radsafety] officers to go beyond the information radsafety plans." Brief for the Appellee at 57. In other words, the test manager authorized the officers to deviate from the plan. Plaintiff argues that because the officers were so authorized, their failure to deviate from the plan subjects the Government to liability. This reasoning

challenge, mirroring the trial court's concerns, goes toward the failure of the plans to specifically prescribe greater monitoring or more diffuse and in-depth information distribution. Plaintiffs' statement that "test site personnel negligently and wrongfully failed to implement basic radiological protection measures which were common at the time," id. at 24 (emphasis added), demonstrates the true character of their allegations. Plaintiffs concede as much by stating that the trial court "determined that the fallout monitoring program and information program which coincided with the 1951-1962 open-air testing at the Nevada test site did not comport with the 'best available scientific knowledge.' " Id. at 42-43 (emphasis added).

In arguing that the safety and information plans themselves are not immune from our review under the discretionary function exception, plaintiffs contend:

> Where Congress has placed a mandatory duty upon the government to protect public health and safety, such as it did upon the Commission, it left no room for further policy-making regarding public safety. Where there is not policy-making there is no "discretion" within the meaning of 28 U.S.C. § 2680(a) and no immunity.

Id. at 13. Essentially, they assert that because the two Atomic Energy Acts demonstrate a concern for public health and safety, even though no specific health and safety measures are mandated therein, the safety plans devised to address that concern involved no social, economic, or political policy making.

On the contrary, the broad safety language of the Atomic Energy Acts had to be translated into concrete plans, and that translation involved the very essence of social, economic, and political decision making—the precise policy choices protected by the discretionary function exception. See General Pub. Util. Corp. v. United States, 745 F.2d 239, 244 (3d Cir. 1984) (means chosen by Nuclear Regula-

---

is at direct odds with Varig Airlines and Dalehite. See supra note 2. It is just such deviation from a discretionary plan that can deprive the action of the protection of the discretionary function exception.

tory Commission to fulfill its broad statutory duty to review safety of nuclear facilities protected by discretionary function exception), cert. denied, 469 U.S. 1228 (1985). These decisions concerned choices involving the social psychology of how best to inform without alarming residents, the most cost-effective way of using public funds to monitor fallout levels, and how best to use a finite number of personnel. In short, they required the AEC "to establish priorities for the accomplishment of its policy objectives by balancing the objectives sought to be obtained against such practical considerations as staffing and funding." Varig Airlines, 467 U.S. at 820. While those choices deviated from the standards against which liability is measured where liability is available, Congress' determination to retain government immunity for "discretionary functions," as understood post-Varig Airlines, puts those choices beyond our ability to review and puts compensation for injury to individuals stemming from those choices beyond our power to order.

While we have great sympathy for the individual cancer victims who have borne alone the costs of the AEC's choices, their plight is a matter for Congress. Only Congress has the constitutional power to decide whether all costs of government activity will be borne by all the beneficiaries or will continue to be unfairly apportioned, as in this case. Until Congress amends the discretionary function exception to the FTCA or passes a specific relief bill for individual victims, we have no choice but to leave them uncompensated. I must therefore concur in the majority opinion which has carefully reviewed and applied the controlling law to the facts of this case.

APPENDIX B

Opinion of the Federal District Court

District of Utah, filed May 10, 1984

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF UTAH

CENTRAL DIVISION

IRENE ALLEN, et al.,	)	Civil No. C 79-0515-J
	)	
Plaintiffs,	)	
	)	
vs.	)	
	)	
UNITED STATES OF AMERICA,	)	MEMORANDUM
	)	OPINION
Defendant.	)	

CONTENTS

I.	INTRODUCTION AND STATEMENT OF THE CASE	1
II.	BACKGROUND: BASIC PRINCIPLES OF RADIATION AND NUCLEAR PHYSICS	10
III.	NUCLEAR FALLOUT	51
IV.	BACKGROUND: BASIC PRINCIPLES OF HEALTH PHYSICS	98
V.	LEGAL ANALYSIS: DISCRETIONARY FUNCTION	130
VI.	LEGAL ANALYSIS: STATUTE OF LIMITATIONS	159
VII.	LEGAL ANALYSIS: THE DUTY ISSUE	178
VIII.	LEGAL ANALYSIS: BREACH OF DUTY	205
IX.	THE QUESTION OF CAUSATION	318
X.	DAMAGES	407
XI.	FINDINGS OF ULTIMATE FACT AND CONCLUSIONS OF LAW	416
	FOOTNOTES	420
	APPENDIX A	466
	APPENDIX B	477
	APPENDIX C	483
	APPENDIX D	488

BRUCE S. JENKINS, JUDGE
UNITED STATES DISTRICT COURT
DISTRICT OF UTAH

(THIS PAGE LEFT BLANK INTENTIONALLY)

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF UTAH

CENTRAL DIVISION

IRENE ALLEN, et al.,	)	Civil No. C 79-0515-J
	)	
Plaintiffs,	)	
	)	
vs.	)	MEMORANDUM
	)	OPINION
UNITED STATES OF AMERICA,	)	
	)	
Defendant.	)	

In a sense this case began in the mind of a thoughtful resident of Greece named Democritus some twenty-five hundred years ago. In response to a question put two centuries earlier by a compatriot, Thales, concerning the fundamental nature of matter, Democritus suggested the idea of atoms. This case is concerned with atoms, with government, with people, with legal relationships, and with social values.

This case is concerned with what reasonable men in positions of decision-making in the United States government between 1951 and 1963 knew or should have known about the fundamental nature of matter.

It is concerned with the duty, if any, that the United States government had to tell its people, particularly those in proximity to the experiment site, what it knew or should have known about the dangers to them from the government's experiments with nuclear fission conducted above ground in the brushlands of Nevada during those critical years.

This case is concerned with the perception and the apprehension of its political leaders of international dangers threatening the United States from 1951 to 1963. It is concerned with high level determinations as to what to do about them and whether such determinations legally excuse the United States from being answerable to a comparatively few members of its population for injuries allegedly resulting from open air nuclear experiments conducted in response to such perceived dangers.

It is concerned with the method and quantum of proof of the cause in fact of claimed biological injuries. It is concerned with the passage of time, the attendant diminishment of memory, the availability of contemporary information about open air atomic testing and the application of a statute of repose.

It is concerned with what plaintiffs—laymen, not experts—knew or should have known about the biological consequences that could result from open air nuclear tests and when each plaintiff knew or should have known of such consequences.

It is ultimately concerned with who in fairness should bear the cost in dollars of injury to those persons whose injury is demonstrated to have been caused more likely than not by nation-state conducted open air nuclear events.

The complaint in this action alleges that each plaintiff, or his predecessor, has suffered injury or death as a proximate result of exposure to radioactive fallout that drifted away from the Nevada Test Site and settled upon communities and isolated populations in southern Utah, northern Arizona and southeastern Nevada. Each of the plaintiffs or their decedents resided in that area. Each claims serious loss due to radiation-caused cancer or leukemia. Each asserts that the injury suffered resulted from the negligence

of the United States in conducting open air nuclear testing, in monitoring testing results, in failing to inform persons at hazard of attendant dangers from such testing and in failing to inform such persons how to avoid or minimize or mitigate such dangers.

A. JURISDICTION

This Court has jurisdiction of this action pursuant to 28 U.S.C. § 1346(b) (1976) and the Federal Tort Claims Act, 28 U.S.C. §§ 2671-2680 (1976). Venue of this action is proper pursuant to 28 U.S.C. § 1402(b) (1976).[1]

The Federal Tort Claims Act (FTCA) is the exclusive legal remedy for claims against the United States "for money damages. . . for. . . personal injury or death caused by the negligent or wrongful act or omission of any employee of the Government while acting within the scope of his office or employment,. . . " This action was tried to the Court, without a jury, pursuant to the requirement of 28 U.S.C. § 2402 (1976) that "[a]ny action against the United States under section 1346 shall be tried by the court without a jury,. . . " See O'Connor v. United States, 269 F.2d 579 (2d Cir. 1959).[2]

B. NATURE OF THE ACTION

This action is a consolidation of the individual claims of the 1,192 named plaintiffs in this lawsuit. This is not a class action. Cf. Annot., 48 A.L.R. Fed. 860 (1980). Trial was held in this action beginning September 14, 1982 and concluding with final arguments on December 17, 1982. The trial encompassed 24 of the claims in their entirety. Pursuant to the suggestion of the court these cases were selected by plaintiffs' and defendant's counsel as "bellwether" cases. The effort was to provide a selection of "typical" cases which when decided and reviewed may provide a legal and factual pattern against which the remaining issues in the pending cases may be subsequently matched.

The trial was conducted as well so as to make a full and complete record concerning legal, historic, and scientific matters common to all of the 1,192 plaintiffs with the idea in mind of avoiding

future duplication of effort. See Park Lane Hosiery Company, Inc. v. Shore, 439 U.S. 322 (1979). Other than as noted in this opinion, this court has not decided the remaining issues in the claims of the more than 1,100 plaintiffs that are still pending in the consolidated case.

This opinion decides claims of individuals, each with his own history and relationship to the open air nuclear tests. It fully decides 24 separate cases, tied together by common legal, historic and scientific threads of unique importance.

C. THE TRIAL

This action has been pending since August 30, 1979. It has been the subject of extensive pre-trial motions, dealt with on a preliminary basis by this Court's earlier opinion. See Allen v. United States, 527 F. Supp. 476 (D.Utah 1981). That opinion in a general way defined the framework for the trial that followed.

Appearances of counsel at the trial, which began on September 14, 1982 and continued for 13 weeks, were as follows:

> For the plaintiffs: Ralph E. Hunsaker, Esq. and David M. Bell, Esq., of O'Connor, Cavanagh, Anderson, Westover, Killingsworth & Beshears, of Phoenix, Arizona; Dale Haralson, Esq. of Haralson, Kinerk & Morey, of Tucson, Arizona; Stewart L. Udall, Esq., of Phoenix, Arizona; and J. MacArthur Wright, Esq. of St. George, Utah.
>
> For the defendant United States: Henry A. Gill, Jr., Esq., Special Attorney, U.S. Department of Justice, Washington, D.C.; Deborah C. Ratner, Esq. and Pamela Wood, Esq., Trial Attorneys, U.S. Department of Justice, Washington, D.C.; Jake Chavez, Esq. and Edward Juran, Esq., Trial Attorneys, U.S. Department of Energy, Washington, D.C.; Ralph H. Johnson, Esq., Assistant U.S. Attorney, Salt Lake City, Utah.

During the course of trial, this court received into evidence the testimony of 98 witnesses as well as more than 1,692 documentary exhibits.[3]

The evidence provides testimony of witnesses ranging from those who participated in the testing program and related operations to highly trained and gifted "experts" offering conflicting opinions, to claimants who seek solace for their test-blamed sorrow.

The record contains historic documents, internal agency memoranda newly declassified, agency directives and correspondence, epidemiological studies, scientific texts and articles, as well as extracts from news media of the day and public information pamphlets.

D. THE PROBLEM OF UNCERTAINTY

We all seek to simplify and to order. The mind eschews the uncertain. We strain for certainty and perfect knowledge in an infinitely complex and dynamic universe. In doing so, we often fail to distinguish between those things which we directly experience, see, feel, hear, taste, smell—facts we experience—from those facts we infer. Each is a form of knowledge. Each we say we know. But we must be constantly aware of the nature of that which we say we "know."

For example, we "know" of the existence of the atom. We "know" of the existence of gamma rays. We have never seen an atom or a gamma ray. We infer that atoms exist. The atom is a mind-created abstract model which provides a convenient, coherent and consistent explanation of an immense collection of perceived effects.[4] It is a model fashioned by many minds after a meticulous sifting of the observed and the reported.[5] But, we remain uncertain still of our scientific certainties.

This court has attempted to formulate an ordered theory of decision. While the effort lacks the mathematical purity of physical theory, it is the judicial resolution of the questions raised by this case with which the court is concerned. The theory of decision melds the method of science with principles of law and public policy.

In doing so, the court endeavors to follow the suggestions of-

fered in a recent address by Chief Judge Howard T. Markey of the U.S. Court of Appeals for the Federal Circuit:

> The differences between the judicial and the scientific-technological processes are profound and pervasive. Failure to recognize that difference has led to judicial expressions of frustration and an unfortunate tendency to rest judicial decisions on current, and often transient, "truths" and "facts" of science and technology. The purpose and function of science is to learn physical facts. . . .
>
> The purpose and function of law is to resolve disputes and to facilitate a structure for the organization of a just society—in a word, to provide justice.
>
> Science normally evolves a new, general physical principle from hypotheses proven by numerous specific experiments. The normal judicial process is precisely the reverse, for, when properly conducted, it applies an existing, generally accepted moral or social value—an ethical principle—a rule of law—to a specific problem. . .
>
> Judges and lawyers must approach with great care, the idea that court decisions can be justified solely on the findings of science, lest the quest for justice be lost along the way.
>
> For the particular "scientific truth" relied upon may prove transient indeed.

Markey, "Needed: A Judicial Welcome for Technology," 79 F.R.D. 209, 210-211 (1979). Judge Markey highlights a premise of this court's theory of decision:

> The first need, then, is to view technological evidence as merely one evidentiary element in the judicial matrix of decision and not necessarily as the sole justification for the judge's legal decision.

Id. at 211 (emphasis in original).

At the core of this case is a fundamental principle—a time-honored rule of law, an ethical rule, a moral tenet:

> [T]he law imposes [a duty] on everyone to avoid acts in their nature dangerous to the lives of others.

Thomas v. Winchester, 6 N.Y. 397, 57 Am. Dec. 455 (1852). The more particularized rules of negligence and proximate cause as a basis for liability which are applied in the body of this opinion are rooted in this principle of duty. In this case, as in any other case in tort law, the answer to the ultimate question: "Who should bear the burden of the risks created by the defendant's conduct?" is ultimately a question of policy and of public values.

In the law, as in science, one always faces uncertainty.[6] This court, faced with the duty of judgment in this case, does not have the luxury of the zealous absolutists who "know beyond doubt" that each and every cancer in the Great Basin is the result of open air atomic testing, or of their absolutist counterparts who "know beyond doubt" that none resulted. The court is disciplined by the record and the application of rules of law.

The court's findings of fact have a certainty that is relative to the evidence presented to the court by others. They are not fixed in absolute terms. Judicial determination of facts in this case is indistinguishable from fact-finding in other cases no matter how "complex" the facts here might be.[7]

Thus, this opinion speaks in terms of "natural and probable" consequences, "substantial" factors and things "more likely than not."

In the pragmatic world of "fact" the court passes judgment on the probable. Dispute resolution demands rational decision, not perfect knowledge.

II.
BACKGROUND: BASIC PRINCIPLES OF RADIATION AND NUCLEAR PHYSICS

Evaluation of the risks and consequences of exposure to atomic radiation in this case demands some familiarity with the concepts of radiation physics and its basic language. Such familiarity is a prelude to the knowledgeable application of rules of law.

It does not come easily. It did not come easily for the court.

The effort of the court has been to set forth as best it can the peculiar language and pertinent concepts of radiation physics as the court understands them from the record, to enable those concerned to understand the legal relationships of the parties as found by the court and the legal consequences of party action.

The synopsis found in the next section of this opinion is part of the judicial effort to understand this case. It does supply some of the reasons why this court has found as it has found and has decided as it has decided. It does supply some of the reasons why the rules of law discussed and applied in subsequent sections have been applied as they have.

A. Scientific Notation and Mathematical Prefixes

Nuclear physics explores the universe using numbers and quantities which range from the extremely large to the infinitesimally small. To simplify the task of using numbers larger than 10 or less than 1, a shorthand system of expression has been devised that relies upon exponential powers of ten. Scientific notation, as this system is called, works in this fashion: Consider, for example, the number 100. One hundred is one way of expressing the quantity 1 $\times$ 100, or 1 $\times$ (10x10). Using exponents, this expression is shortened to $1x10^2$, which still means 100. Similarly, 1,000 (1x10x10x10) may be expressed as $1x10^3$ (or simply 10^3) one million (1,000,000) as $1x10^6$ (or 10^6) and so forth. More complex numbers may be expressed in this fashion:

$$6{,}205{,}000{,}000 = 6.205 \times 10^9$$
$$1{,}899{,}205 = 1.899205 \times 10^6$$

$$89{,}450{,}000{,}000{,}000 = 8.945 \times 10^{13}$$

Decimal fractions may be expressed in scientific notation as well. For example, 0.01 equals 1/100 or, as we have seen $1/10^2$. The common form of stating this fraction in scientific notation is $1x10^{-2}$, or 10^{-2}. Thus a negative exponent indicates a fractional quantity while a positive exponent indicates a value greater than 1.[8]

Consider the following examples:

(1) $0.0032 = 32/10{,}000 = 32/10^4 = 32 \times 10^{-4}$ or, more commonly, 3.2×10^{-3}

(2) $0.65 = 65/100 = 65/10^2 = 65 \times 10^{-2}$ or 6.5×10^{-1}

(3) $0.000042 = 42/1{,}000{,}000 = 42/10^{-6}$ or 4.2×10^{-5}

Scientific notation proves extremely useful in performing mathematical operations involving very large or very small numbers. Multiplication is accomplished through simple multiplication of the initial terms and through addition of the exponential terms. For example,

$$(1)\ 6{,}500{,}000 \times 42{,}120{,}000{,}000 = ?$$

Switching to scientific notation gives us

$$(6.5 \times 10^6) \times (4.212 \times 10^{10}) = ?$$

which is computed in this fashion:

$$(6.5 \times 4.212) \times 10^{(6+10)} = 27.378 \times 10^{16}$$

or, expressed in simplest form, 2.7378×10^{17}. This expression seems far simpler to write than 273,780,000,000,000,000, which is the more conventional form. Fractions are multiplied in the same fashion:

$$(1)\ 1.2 \times 10^{-4} \times 6.88 \times 10^{-12} = ?$$
$$(1.2 \times 6.88) \times 10^{(-4)+(-12)} = 8.256 \times 10^{-16},$$

a number expressed conventionally as .0000000000000008256.

Division of numbers expressed in scientific notation is accomplished in a parallel way:

$$(1)\ 6.2 \times 10^6 \div 3.8 \times 10^2 = ?$$
$$(6.2 \div 3.8) \times 10^{(6-2)} = 1.6315789 \times 10^4$$

(2) $3.2 \times 10^{18} \div 4.5 \times 10^{11} = ?$
$(3.2 \div 4.5) \times 10^{(18-11)} = .71111 \times 10^{7}$ or
7.111×10^{6}—a short way of saying 7,111,000.
(3) $1.62 \times 10^{-2} \div 6.04 \times 10^{6} = ?$
$(1.62 \div 6.04) \times 10^{((-2)-6)} = .2682 \times 10^{-8}$ or
2.682×10^{-9}—a short way of writing 0.000000002682.

Numbers such as these are commonplace in nuclear physics. For example, Planck's Constant, a fixed number defining the proportional relationship between the frequency of a light wave and its energy, is expressed as $6.6261965 \times 10^{-34}$, a term far more easily handled in computations than is 0.00000000000000000000000000000000066261965, its conventional equivalent.[9] Scientific notation makes it possible for a small electronic calculator with an eight-digit or ten-digit display to calculate numbers ranging from 10^{99} to 10^{-99}. Mathematical operations beyond either limit of that range have no practical value: nothing in our experience is either that large or that small.[10]

The mathematics used in nuclear physics is simplified for practical purposes through use of scientific notation. Another system of simplification involves units of measurements routinely used by humans in describing matter, energy and their interactions. At this point in history, science maintains a preference for units in the metric system. Mass is measured in grams, length in units called meters, volume in litres, energy in units such as ergs or joules. Often, calculations are made in terms of very large or very small quantities—thousands of units or infinitesimal fractions of units. One may be working with a thousand grams or a million grams or with a billionth of a gram. A system of word prefixes has been devised under the International System of Units to adjust units to more closely relate to the actual quantities being utilized. Table 1 lists these prefixes and their definitions.

Thus, when one is working with 6×10^{3}, or 6,000 grams, one is also working with 6 kilo grams. Likewise, if the quantity is 0.000000082 grams, or 8.2×10^{-8} g, a more workable expression may be 8.2×10^{-2} or .0820 micrograms (μg). As will be seen, it is not uncommon to speak of micrograms, or picocuries (a tiny unit of radioactivity) of fallout material deposited in human bodies, or

of kilograms of material, or megacuries of fallout radioactivity generated by detonation of a nuclear weapon.[12] The difference between a picocurie of radioactivity and a megacurie of radioactivity is a factor of 10^{18} or 1,000,000,000,000,000,000.[13] Yet both units are meaningful to the evidence in the record before this court. See Part IV(A), infra.

TABLE 1. Prefixes for the Units in the International System[11]

Prefix	Symbol	Power
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	K	10^{3}
hecto	L	10^{2}
deka	da	10^{1}
deci	d	10^{-1} or 1/10
centi	c	10^{-2} or 1/100
milli	m	10^{-3} or 1/1,000
micro	μ	10^{-6} or 1/1,000,000
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Simply by referring to Table 1, one can determine what multiple or fraction of a standard unit is being discussed in the text. Quick reference to Table 1 prefixes will aid the reader in identifying the units used and in making a meaningful comparison of quantities.

B. The Atom: Protons, Neutrons and Electrons

After centuries of careful observation, our best answer to Thales' 2,500-year-old question "What is the world made of?" seems to be that all matter is composed of atoms. See G. Amaldi, The Nature of Matter (1966). Atoms are very tiny packages of mass which have specific physical qualities.[14] In the natural world around us, science has identified 92 species of atoms commonly referred to as elements. Each element has unique physical and chemical properties. Each element's atoms differ slightly in structure and composition from the atoms of any other element. Some elements are familiar: copper, iron, oxygen, gold, carbon, calcium and two dozen others are well known as part of our own chemical

makeup, or as part of the everyday world around us. Others, such as praseodymium, rubidium, and polonium, are far more obscure. Each, however, represents a different type of atom.

In addition to the 92 "natural" elements, scientists have produced a dozen more "synthetic" elements, such as plutonium, which are heavier, and often more unstable and short-lived than their "natural" brethren.[15] A complete list of the known chemical elements is found in Table 2.

Table 2 THE ELEMENTS*

Atomic Number	Element's Name	Chemical Symbol	Atomic Number	Element's Name	Chemical Symbol
1	Hydrogen	H	33	Arsenic	As
2	Helium	He	34	Selenium	Se
3	Lithium	Li	35	Bromine	Br
4	Beryllium	Be	36	Krypton	Kr
5	Boron	B	37	Rubidium	Rb
6	Carbon	C	38	Strontium	Sr
7	Nitrogen	N	39	Yttrium	Y
8	Oxygen	O	40	Zirconium	Zr
9	Fluorine	F	41	Niobium	Nb
10	Neon	Ne	42	Molybdenum	Mo
11	Sodium	Na	43	Technetium	Tc
12	Magnesium	Mg	44	Ruthernium	Ru
13	Aluminum	Al	45	Rhodium	Rh
14	Silicon	Si	46	Palladium	Pd
15	Phosphorus	P	47	Silver	Ag
16	Sulfur	S	48	Cadmium	Cd
17	Chlorine	Cl	49	Indium	In
18	Argon	Ar	50	Tin	Sn
19	Potassium	K	51	Antimony	Sb
20	Calcium	Ca	52	Tellurium	Te
21	Scandium	Sc	53	Iodine	I
22	Titanium	Ti	54	Xenon	Xe
23	Vanadium	V	55	Cesium	Cs
24	Chromium	Cr	56	Barium	Ba
25	Manganese	Mn	57	Lanthanum	La
26	Iron	Fe	58	Cerium	Ce
27	Cobalt	Co	59	Praseodymium	Pr
28	Nickel	Ni	60	Neodymium	Nd
29	Copper	Cu	61	Promethium	Pm
30	Zinc	Zn	62	Samarium	Sm
31	Gallium	Ga	63	Europium	Eu
32	Germanium	Ge	64	Gadolinium	Gd

Table 2 *(continued)*

Atomic Number	Element's Name	Chemical Symbol	Atomic Number	Element's Name	Chemical Symbol
65	Terbium	Tb	86	Radon	Rn
66	Dysprosium	Dy	87	Francium	Fr
67	Holmium	Ho	88	Radium	Ra
68	Erbium	Er	89	Actinium	Ac
69	Thulium	Tm	90	Thorium	Th
70	Ytterbium	Yb	91	Protactinium	Pa
71	Lutetium	Lu	92	Uranium	U
72	Hafnium	Hf	93	Neptunium	Np
73	Tantalum	Ta	94	Plutonium	Pu
74	Tungsten	W	95	Americium	Am
75	Rhenium	Re	96	Curium	Cm
76	Osmium	Os	97	Berkelium	Bk
77	Iridium	Ir	98	Californium	Cf
78	Platinum	Pt	99	Einsteinium	Es
79	Gold	Au	100	Fermium	Fm
80	Mercury	Hg	101	Mendelevium	Md
81	Thallium	Tl	102	Nobelium	No
82	Lead	Pb	103	Lawrencium	Lw
83	Bismuth	Bi	104	(Kurchatovium)	Ku
84	Polonium	Po	105	(Hahnium)	Ha
85	Astatine	At			

*See also Appendix D, infra.

The differences between atoms of different elements are accounted for by variations in their composition and structure. All atoms are thought to be composed of three types of smaller particles: protons, neutrons and electrons. A proton is a tiny particle with a mass of approximately 1.672×10^{-24} gm, or 1.007 atomic mass units.[16] Each proton carries a positive electric charge.[17] An electron is a particle with a negative electric charge equivalent to that of a proton but with 1/1837 the mass of a proton, or 5.5×10^{-4} amu. An electron has a diameter of approximately 1×10^{-12} cm. A neutron is a subatomic particle having no electric charge (hence the name) yet having a mass of 1.0087 amu—slightly heavier than a proton. An atom of a particular element represents a specific combination of protons, neutrons and electrons.

Far from being randomly distributed within an atom, these particles are ordered according to specific principles of structure:

(1) Each atom contains a nucleus at its center;

(2) Protons and neutrons are located within the nucleus;

(3) The nucleus is tiny in relation to the atom itself, comprising about 1/100,000th of the volume of the atom, yet containing almost all of its mass;

(4) Electrons orbit the nucleus in constant motion, and in patterns better described using the physics of standing waves;[18]

(5) An electrostatically neutral atom is one with an equal number of electrons and protons; an atom with an imbalance of protons and electrons will itself act as a charged particle, called an ion. Ions—electrically charged atoms—are often far more reactive with other atoms than are neutral, un-ionized atoms;

(6) Electrons are distributed in the space around the nucleus in stable orbitals, which correspond to a discrete amount of energy, often called an energy state;

(7) Only certain energy states, or orbitals, are allowed in atoms of a given element;

(8) An electron may move from one energy level to a higher energy level, by absorbing energy from an outside source in an amount equal to the difference between the two energy levels; an electron may fall to a lower energy level by emitting energy in the amount of the difference between the two levels. The energy is emitted in the form of a photon.[19]

An electron may absorb energy (i.e., become "excited") to a degree sufficient to allow it to leave the atom altogether. This phenomenon is called ionization, and is the key to innumerable chemical reactions.

The simplest element is hydrogen, whose atoms consist of a single proton in the nucleus and a single electron in the surrounding orbitals. The number of protons in the nucleus determines the number of electrons in the atom's orbital shells, which has a

significant effect on the atom's chemical characteristics. The number of protons is often referred to as the atomic number and is identified in the literature by the symbol Z. An element's atomic number determines its place in an important scheme of classification known as the Periodic Table. See Table 3. The elements in each column grouping, or period, share similar electron structures, physical and chemical properties. See I. Asimov, Understanding Physics: The Electron, Proton, and Neutron 13-18 (1966); C. Hammond, "The Elements," in Handbook of Chemistry and Physics, pp. B-2 to B-40 (64th ed. Weast 1983).

In addition to the atomic number, atoms are described according to atomic weight, symbolized by the letter A, which quantifies the total mass of an atom as expressed in atomic mass units (amu). The atomic weight of hydrogen is approximately 1.00797 amu, the single proton being the source of almost all of its mass. Heavier elements have nuclei containing neutrons as well as more protons. Helium, for example, has two protons and (usually) two neutrons in its nucleus, giving it an atomic number (Z) of 2 and atomic weight (A) of approximately 4.0026. While varying the number of protons will change the atom from one element to another, varying the number of neutrons changes the atomic weight of the atom without radically affecting its physical or chemical properties. Atoms of the same element which have different numbers of neutrons in the nucleus are referred to as isotopes of the element. Hydrogen, for example, has three isotopes: the most common form, protium, has no neutrons; deuterium, or heavy hydrogen, has one proton and one neutron; tritium, the heaviest, has two neutrons for each proton. Isotopes are often referred to by an abbreviation of their atomic weights called a mass number. Radium (Z = 88, A = 226.054) becomes simply radium 226 or ^{226}Ra. Radium 224 (A = 224.0202) is another isotope of the same element having two less neutrons. In lighter elements the number of neutrons and protons in the nucleus tends to be equal, or nearly so. In the heavier elements toward the bottom of the Periodic Table, neutrons outnumber protons. Lead, for example, has 82 protons (Z = 82) and an average of 115 neutrons (A = 207.19) in its nuclei, compared to Calcium (Z = 20, A = 40.08) or Neon (Z = 10, A = 20.183).

PERIODIC TABLE OF THE ELEMENTS

1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0
1 +1 H 1.00797 1															**2** 0 He 4.0026 2
3 +1 Li 6.939 2 1	**4** +2 Be 9.0122 2 2									**5** +3 B 10.811 2 3	**6** +2 +4 C 12.01115 2 4	**7** +1 +2 +3 +4 +5 N 14.0067 2 5	**8** 2 O 15.9994 2 6	**9** 1 F 18.9984 2 7	**10** 0 Ne 20.183 2 8
11 +1 Na 22.9898 2 8 1	**12** +2 Mg 24.312 2 8 2									**13** +3 Al 26.9815 2 8 3	**14** +2 +4 Si 28.086 2 8 4	**15** +3 +5 P 30.9738 2 8 5	**16** +4 +6 S 32.064 2 8 6	**17** +1 +5 +7 Cl 35.453 2 8 7	**18** 0 Ar 39.948 2 8 8
19 +1 K 39.102 8 8 1	**20** +2 Ca 40.08 8 8 2	**21** +3 Sc 44.956 8 9 2	**22** +2 +3 +4 Ti 47.90 8 10 2	**23** +2 +3 +4 +5 V 50.942 8 11 2	**24** +2 +3 +6 Cr 51.996 8 13 1	**25** +2 +3 +4 +6 +7 Mn 54.9380 8 13 2	**26** +2 +3 Fe 55.847 8 14 2	**27** +2 +3 Co 58.9332 8 15 2	**28** +2 +3 Ni 58.71 8 16 2	**29** +1 +2 Cu 63.546 8 18 1	**30** +2 Zn 65.37 8 18 2	**31** +3 Ga 69.72 8 18 3	**32** +2 +4 Ge 72.59 8 18 4	**33** +3 +5 As 74.9216 8 18 5	**34** +4 +6 Se 78.96 8 18 6	**35** +1 +5 Br 79.904 8 18 7	**36** 0 Kr 83.80 8 18 8
37 +1 Rb 85.47 18 8 1	**38** +2 Sr 87.62 18 8 2	**39** +3 Y 88.905 18 9 2	**40** +4 Zr 91.22 18 10 2	**41** +3 +5 Nb 92.906 18 12 1	**42** +6 Mo 95.94 18 13 1	**43** +4 +6 +7 Tc (97) 18 13 2	**44** +3 Ru 101.07 18 15 1	**45** +3 Rh 102.905 18 16 1	**46** +2 +4 Pd 106.4 18 18 0	**47** +1 Ag 107.868 18 18 1	**48** +2 Cd 112.40 18 18 2	**49** +3 In 114.82 18 18 3	**50** +2 +4 Sn 118.69 18 18 4	**51** +3 +5 Sb 121.75 18 18 5	**52** +4 +6 Te 127.60 18 18 6	**53** +1 +5 +7 I 126.9044 18 18 7	**54** 0 Xe 131.30 18 18 8
55 +1 Cs 132.905 18 8 1	**56** +2 Ba 137.34 18 8 2	**57*** +3 La 138.91 18 9 2	**72** +4 Hf 178.49 32 10 2	**73** +5 Ta 180.948 32 11 2	**74** +6 W 183.85 32 12 2	**75** +4 +6 +7 Re 186.2 32 13 2	**76** +3 +4 Os 190.2 32 14 2	**77** +3 +4 Ir 192.2 32 15 2	**78** +2 +4 Pt 195.09 32 16 2	**79** +1 +3 Au 196.967 32 18 1	**80** +1 +2 Hg 200.59 32 18 2	**81** +1 +3 Tl 204.37 32 18 3	**82** +2 +4 Pb 207.19 32 18 4	**83** +3 +5 Bi 208.980 32 18 5	**84** +2 +4 Po (209) 32 18 6	**85** At (210) 32 18 7	**86** 0 Rn (222) 32 18 8
87 +1 Fr (223) 18 8 1	**88** +2 Ra (226) 18 8 2	**89**** +3 Ac (227) 18 9 2													

Atomic Number · Symbol · Atomic Weight — **50** +2 +4 Sn 118.69 18 18 4 — Oxidation States; KEY TO CHART; Electron Configuration

Transition Elements — Group 8 — Transition Elements

*Lanthanides	**58** +3 +4 Ce 140.12 20 8 2	**59** +3 Pr 140.907 21 8 2	**60** +3 Nd 144.24 22 8 2	**61** +3 Pm (145) 23 8 2	**62** +2 +3 Sm 150.35 24 8 2	**63** +2 +3 Eu 151.96 25 8 2	**64** +3 Gd 157.25 25 9 2	**65** +3 Tb 158.924 27 8 2	**66** +3 Dy 162.50 28 8 2	**67** +3 Ho 164.930 29 8 2	**68** +3 Er 167.26 30 8 2	**69** +3 Tm 168.934 31 8 2	**70** +2 +3 Yb 173.04 32 8 2	**71** +3 Lu 174.97 32 9 2	
**Actinides	**90** +4 Th (232) 18 10 2	**91** +5 +4 Pa (231) 20 9 2	**92** +3 +4 +5 +6 U (238) 21 9 2	**93** +3 +4 +5 +6 Np (237) 22 9 2	**94** +3 +4 +5 +6 Pu (244) 24 8 2	**95** +3 +4 +5 +6 Am (243) 25 8 2	**96** +3 Cm (247) 25 9 2	**97** +3 +4 Bk (247) 27 8 2	**98** +3 Cf (251) 28 8 2	**99** Es (254) 29 8 2	**100** Fm (257) 30 8 2	**101** Md (256) 31 8 2	**102** No (254) 32 8 2	**103** Lw 32 9 2	**104** 32 10 2

Numbers in parentheses are mass numbers of most stable isotope of that element

No. C 79-0515-J

C. Radiation and Radioactivity

Perhaps the simplest definition of radiation is the one most easily understood: radiation is a transfer of energy through space (or some other accommodating medium). Usually energy is radiated in the form of light or heat, though as we shall see, energy can be radiated through emission of particles having momentum.[20]

Despite its outward appearance, light—or more broadly, electromagnetic radiation—is not transmitted as a continuous flow of energy. When light is radiated, its energy is packaged in discrete units,[21] tiny bundles of energy called photons. Careful observation has disclosed that photons have some properties which are best explained if they are considered as waves; other properties are best explained if photons of light are thought of as particles. The energy of a particular photon, or light wave particle, is related to its frequency as follows:

$$E = hv$$

When E is energy (in ergs), v is the frequency (in Hertz) and h is a number known as Planck's Constant. See note 9, supra. The relationship may also be described in terms of wavelength.

$$E = h\left(\frac{c}{\lambda}\right)$$

E is energy
h is Planck's constant
c is the speed of light
λ is the wavelength

In short, the higher the frequency (or the shorter the wavelength) of light, the greater its energy. Visible light falls roughly midway on the spectrum of light energy with wavelengths [λ]ranging from 7×10^{-5} cm for red light through 4×10^{-5} cm for violet. Wavelengths longer than those for visible light fall toward the infrared end of the spectrum: radar waves, radio waves, and microwaves have photons of less energy than visible light. Light wave particles of greater energy range from ultraviolet light having sufficient energy to cause sunburn ($\lambda \sim 10^{-6}$ cm) to x-rays, gamma rays ($\lambda \sim 10^{-8}$ to 10^{-10} cm) and high energy cosmic rays ($\lambda > 10^{-12}$ cm) which are of particular interest to this lawsuit.

Differences in photon energy are crucial. We are constantly awash in an invisible ocean of radio waves which pass by—and through—our bodies with no perceivable harmful effect. However, exposure to gamma rays, which easily may be one-hundred trillion (10^{14}) times more powerful than broadcast radio waves, raises serious human health concerns. See Part IV, infra.

At the end of the last century, scientists in Europe led by Wilhelm Roentgen discovered basic techniques for producing high energy photons—"x-rays," Roentgen called them—in the laboratory. By bombarding a metal plate within a sealed glass vacuum tube with high-voltage electrons, invisible radiation was produced which would cause certain chemicals to fluoresce brilliantly, and which could fog or darken photographic plates wrapped in paper, or even concealed within a box. See S. Glasstone, Sourcebook on Atomic Energy 48-51 (2d ed. 1958); I. Asimov, Understanding Physics: The Electron, Proton and Neutron 33-35 (1966). In 1896, the French physicist Henri Becquerel discovered that the same kind of penetrating radiation emanated from uranium salts.[22] In 1898, Marie Curie gave this phenomenon of constant emission of penetrating, ionizing radiation the name radioactivity. S. Glasstone, Sourcebook on Atomic Energy, at 53; see Mme. Sklodowska-Curie, 126 Comptes Rendus 1101 (1898). One of the first properties observed in both x-rays and radioactive substances was the induction of an electrical charge in the air surrounding an x-ray tube or immediately in contact with a sample of radioactive material. This ionizing effect enabled early researchers to detect such radiation using very simple devices. "[T]o detect nuclear particles we detect ionization." E. Pollard & W. Davidson, Applied Nuclear Physics 43 (1942) (emphasis in original). Radiation detection and measurement techniques are still very heavily dependent upon this particular quality. See e.g., N. Tsoulfanidis, Measurement and Detection of Radiation (1983).[23] As we shall see, the adverse health effects of exposure to radiation are also a product of ionization. See Part IV infra.

D. Ionizing Radiation: Alpha, Beta, and Gamma Rays.

Early research work done by Ernest Rutherford and others using heavy radioactive elements such as radium, polonium, thorium

and uranium, disclosed that ionizing radiation emanating from radioactive materials could be resolved into three different types: alpha rays (α), beta rays (β) and gamma rays (γ). Application of a strong magnetic field to a stream of ionizing radiation emitted by a sample of radium salts readily deflected beta rays in a fashion indicating that beta radiation carries a negative charge. See Fig. 1. Less easily deflected in the opposite direction were alpha rays, which were deduced to have a positive electrostatic charge and greater momentum than beta rays. Gamma rays passed undeflected by the strongest magnetic fields; their highly penetrating qualities led researchers to conclude that gamma rays and x-rays were very similar (which they are). See e.g., J. Cork, Radioactivity and Nuclear Physics 11 (1947). Soon it was determined that beta rays exhibited all the properties of high-energy electrons, while alpha rays were identified as consisting of the nuclei of helium atoms stripped of both outer electrons. Both gamma rays and x-rays were found to consist of very short wavelength high-energy photons.[24]

Of crucial importance was the discovery that radioactivity is the product of internal processes within the nucleus of the atom rather than the result of excitation by some undetected outside source of energy. Radioactivity properties are unaffected by external forces, such as heat, light or pressure, or by any chemical reaction.[25] Instead, they operate according to specific principles of nuclear physics.

The basic principle finds simple expression in the work of Pollard and Davidson: "This process, the passage from one nearly stable nucleus to one which is stable, is the underlying process of radioactivity." Applied Nuclear Physics 102 (1942). Recalling that the nuclei of atoms are made up of various combinations of protons and neutrons, and that within atoms of a given element, the ratio of neutrons to protons may vary from isotope to isotope, careful observation of radioactive properties reveals that some proton/neutron ratios tend to be far more stable than others. Radioactivity represents the mechanism of internal adjustment by which less stable nuclei transform their composition into a proton/neutron ratio having greater stability. Emission of an alpha particle, for example, lightens the nucleus in evenhanded fashion; the numbers of neutrons and protons are each reduced by 2. Radio-

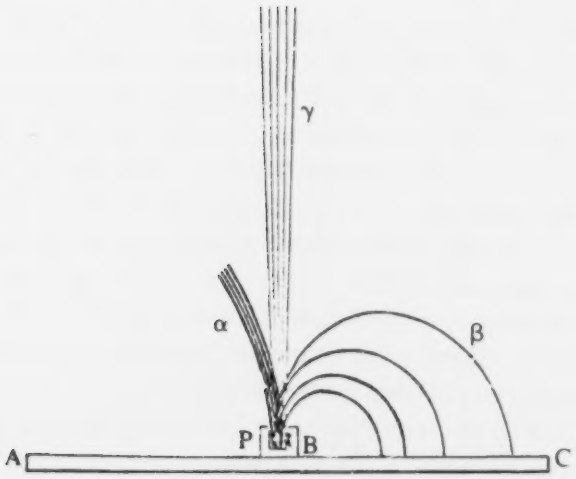


FIG. 4.

I. The α-rays are very slightly penetrating, and appear to constitute the principal part of the radiation. These rays are characterised by the laws by which they are absorbed by matter. The magnetic field acts very slightly upon them, and they were formerly thought to be quite unaffected by the action of this field. However, in a strong magnetic field, the α-rays are slightly deflected; the deflection is caused in the same manner as with cathode rays, but the direction of the deflection is reversed: it is the same as for the canal rays of the Crookes tubes.

II. The β-rays are less absorbable as a whole than the preceding ones. They are deflected by a magnetic field in the same manner and direction as cathode rays.

III. The γ-rays are penetrating rays, unaffected by the magnetic field, and comparable to Röntgen rays.

Consider the following imaginary experiment:—Some radium, R, is placed at the bottom of a small deep cavity, hollowed in a block of lead, P (Fig.4). A sheaf of rays, rectilinear and slightly expanded, streams from the receptacle. Let us suppose that a strong uniform magnetic field is established in the neighbourhood of the receptacle, normal to the plane of the figure and directed towards the back. The three groups of rays, α, β, γ, will now be separated. Then rather faint γ-rays continue in their straight path without a trace of deviation. The β-rays are deflected in the manner of cathode rays, and describe circular paths in the plane of the figure. If the receptacle is placed on a photographic plate, A C, the portion, B C, of the plate which receives the β-rays is acted upon. Lastly, the α-rays form a very intense shaft which is slightly deflected, and which is soon absorbed by the air. These rays describe in the plane of the figure a path of great curvature, the direction of the deflection being the reverse of that with the β-rays.

If the receptacle is covered with a thin sheet of aluminium (0.1 m.m. thick), the α-rays are suppressed almost entirely, the β-rays are lessened, and the γ-rays do not appear to be absorbed to any great extent.

Fig. 1. Mme. Marie Sklodowska Curie, Radioactive Substances, thesis presented to the Faculty of Sciences, Paris, 1903 (pap. reprint ed. 1961), at 33-34.

active transformation by α-particle emission is observed most often in the decay of heavy elements ($Z>84$),[26] such as uranium ($Z = 92$, $A = 238$), which ultimately "decay" to the very stable nuclear structure found in lead 206 ($Z = 82$, $A = 206$):

$$^{210}_{84}Po \longrightarrow {}^{206}_{82}Pb + {}^{4}_{2}He \text{ (α-particle)}$$

A nucleus which has a greater ratio of neutrons to protons than is found in more stable forms may emit a beta particle (β-)—a high energy negative electron—as one of the neutrons is transformed into a proton. Strontium-90, with 38 protons and 52 neutrons, is radioactive. It decays by β-emission into Yttrium-90, with 39 protons and 51 neutrons. Yttrium-90 in turn decays into Zirconium-90 by β-emission. Zirconium-90 with 40 protons to 50 neutrons, is the stable, naturally predominate isotope of that element. Radioactivity ceases.

$$^{90}_{38}Sr \xrightarrow{\beta} {}^{90}_{39}Y \xrightarrow{\beta} {}^{90}_{40}Zr \text{ (stable)}$$

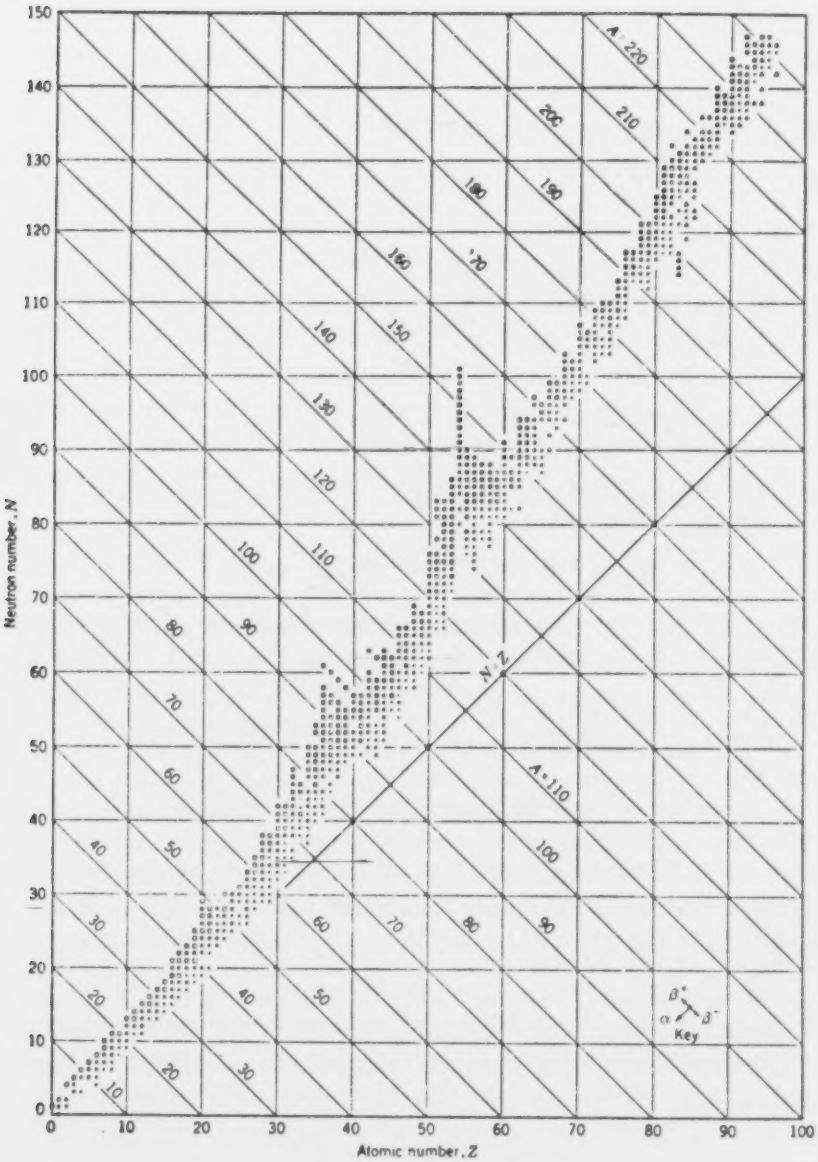
Atoms with an overabundance of protons may decay by emitting a positively charged electron, or positron (β+), or by capturing an electron from a nearby orbital. Either process reduces the number of protons and increases the number of neutrons by 1. For example,

$$^{14}_{8}O \longrightarrow {}^{14}_{7}N \text{ (stable)} + \beta+ \text{ (positron)}$$

When the radioactivity properties of the nuclides[27] are plotted on a graph of numbers of neutrons (N) and protons (Z), a pattern emerges. See Fig. 2.

Radioactive decay enhances nuclear stability not only by adjusting the total number of particles, but also by carrying away discrete bundles, or quanta, of energy from the nucleus. Alpha particles don't quietly drift away from the nucleus of Plutonium-239; they are propelled away at high speed with an energy of more than 5 MeV—five million electron volts. While 5 MeV is a trifling amount of energy in the sphere of human endeavors, at the atomic level it is enormous. In 1919, Rutherford bombarded nitrogen atoms with α particles of lesser energy. The α particles slammed into the nitrogen nuclei, yielding oxygen nuclei—a different element—and a free proton:

$$^{4}_{2}He \text{ (α particle)} + {}^{14}_{7}N \longrightarrow {}^{17}_{8}O + {}^{1}_{1}H \text{ (proton)}$$



A nuclidic chart.

- stable.
- z negatron emitter.
- x positron emitter (or electron capture).
- Δ alpha emitter.

Where a nuclide has more than one mode of disintegration, the predominant mode has been used. The sloping lines represent constant A values (isobars).

Fig. 2. D. Halliday, Introductory Nuclear Physics 9 (1950).

E. Pollard & W. Davidson, Applied Nuclear Physics 5-6 (1942).

A nucleus may also expel energy through emission of a gamma ray (γ) of a particular wavelength. Likelihood of gamma emission depends on the specific nuclides. Strontium-90 does not emit gamma rays during decay. Iodine-131 does. Cobalt-60 emits two gamma rays in the MeV range, and has been used as an important source of radiation in the treatment of cancer. The detailed properties and mechanics of radioactivity and nuclear transformations are as awe-inspiring as they are complex. Why it is, for example, that unstable heavy nuclei emit α particles poses a challenging theoretical question, the answer to which is beyond the scope of this inquiry.[28] Yet a specific understanding of the statistical behavior of radionuclides (e.g., concepts such as radionuclide "half-life") and of the ways in which ionizing radiation interacts with other matter is crucial to adequate analysis of the causation and negligence issues raised in this action.

E. Statistical Nature of Radioactivity

Current theory holds that events at the atomic or sub-atomic level occur according to statistical probabilities rather than any strict determinism.[29] Radioactive decay in any given quantity of a radioactive element occurs at a constant rate, yet no one can tell at what time any particular atom will decay. We know only the probability that it will decay within a chosen time period, or viewed another way, that over a chosen period of time, x number of nuclei in our sample will decay into "daughter" nuclides. The most important expression of this statistical approach is found in the concept of half-life. The half-life of a radionuclide is the specific length of time during which half of the nuclei in any amount of the radionuclide will have decayed. For example, if you start with a one gram sample of radium-226 (^{266}Ra), after 1,600 years only half of the sample (0.5 gm) remains ^{226}Ra. The other half has undergone radioactive decay:

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He} + \text{Q (energy)}$$

After another 1,600 years, only half of that remainder is still ^{226}Ra (0.25 gm). Passage of 1,600 more years witnesses decay of one-half of that fraction, leaving 1/8 gram (0.125 gm) of ^{226}Ra.

The process of decay continues at this rate until no more ^{226}Ra remains. To say, therefore, that a radionuclide such as strontium-90 has a half-life of 28.1 years means that half of the quantity existing at the beginning of the 28.1 years remains $^{90}_{38}Sr$ at the end of that time.

Half-life varies dramatically from radionuclide to radionuclide. Some isotopes last for half-lives of only a few seconds; others last far longer. Uranium ($^{238}_{92}U$), although radioactive, has a half-life of 4.51×10^9 years—nearly the age of the earth itself. See R. Heath, "Table of the Isotopes," in Handbook of Chemistry and Physics B-232 to B-316 (64th ed. Weast 1983).[30] Half-life is indicative not only of the persistence of a radionuclide in the laboratory or the environment, but also of the intensity of its radioactive decay. Radiation yielded by one gram of iodine-136, an isotope found in the fireball of a nuclear explosion, is intense: emitting β particles and γ rays in the MeV range, ^{136}I decays rapidly, reflecting a half-life of 83 seconds.

$$^{136}_{53}I \dashrightarrow {}^{136}_{54}Xe \text{ (stable)} + \beta - + \gamma + Q \text{ (energy)}$$

Consequently its radioactivity fades rapidly. After 15 minutes, less than 1/2000 of the original amount is identifiable as ^{136}I. After an hour more, the fraction remaining is nearly 2.28×10^{-15} of the original amount. In contrast, Plutonium-239, a radionuclide present in every nuclear fallout cloud to date,[31] persists with a half-life of 24,400 years. Consequently, all but a fraction of the estimated 3 tons of ^{239}Pu deposited on the earth by fallout can still be found somewhere. See "Sources and Effects of Ionizing Radiation." Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (1977), PX-706/DX-605 [hereinafter cited as the UNSCEAR Report (1977)], at 148.

Half-life is not an average lifetime for a radionuclide;[32] it is an expression of rate, of the statistical probability of decay over a specific time period

> The half-life of a radionuclide gives some immediate insight into its behavior and the nature of the hazard that might be associated with it. A small quantity of radionuclide with a half-life in the order of minutes will not persist long enough

to present a significant hazard a few days later and it is not likely to become dispersed very far by natural forces. In contrast, a radionuclide with a half-life on the order of several years may represent a long-term hazard and become widely dispersed if not held in containment. . . .

F. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment 44 (1982). The quantity of radioactive material that persists in relation to the number of half-lives is illustrated in Fig. 3.

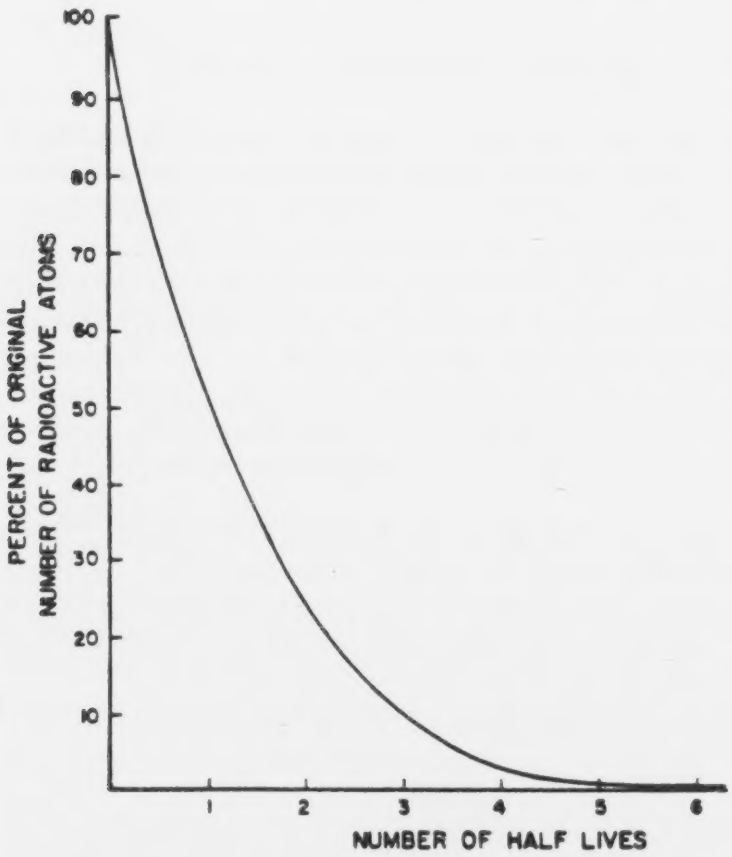


Fig. 3. Relationship of time, expressed as number of half-lives, to the quantity of a radioactive substance.

Quantity of radioactive material may be expressed in either of two ways: (1) the mass of the material; or (2) its radioactivity. To

say, however, that a sample of Strontium-90 has a mass of *x* grams does not by itself offer any perspective on the amount of ionizing radiation being emitted by the sample at any given moment. The activity of a known mass of radioactive material may be computed as follows:

$$A^* = \frac{0.693mN_A}{T_{1/2}AF_t}$$

Where A* is the activity of the sample;
m is the mass of the sample;
A is the atomic weight of the radionuclide;
$T_{1/2}$ is the half-life in years (or whatever);
F_t is the conversion factor from years (or whatever) to a desired time period, e.g. minutes; seconds, etc.

N_A is a constant, known as Avogadro's number, expressing the number of atoms in a mole (a mass in grams equal to the nuclide's atomic weight) of material. See F. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment, supra at 45. For example, a 1.2 gram sample of sodium-24, an important radioactive by-product of nuclear weapons testing having a half-life of 15.0 hours, would have an initial activity of

$$A^* = \frac{(0.693)(1.2 \text{ grams})(6.022 \times 10^{23} \text{ atoms/moles})}{(15.0 \text{ hours})(24 \text{ grams/mole})(3600 \text{ seconds/hr.})}$$
$$= 3{,}864 \times 10^{17} \text{ disintegrations per second.}$$

This activity represents a rate of emission paralleling that of a sample of pure radium-226 having a mass of 1.0557 x 10^7 grams, or 10.5 metric tons. Of course, ^{24}Na activity would fade quickly in comparison to the ^{226}Ra; the mean life of ^{24}Na atoms would be 21.64 hours, while atoms in our 10.5 metric tons would persist for a mean life of 2,308.8 years, making it a far more serious hazard overall.[33]

Expression of radioactivity in terms of rate of decay (e.g., disintegrations per second) is a common measurement. The most frequently used unit of activity is the curie (Ci), which represents a mass undergoing 3.7 x 10^{10} disintegrations per second. Practical quantities of radioactive materials are more easily expressed in fractional units, such as millicuries (mCi), microcuries (μCi), or picocuries (pCi), representing 10^{-3}, 10^{-6} and 10^{-12} curies, respec-

tively.[34] A tiny new unit, the Becquerel (Bq), represents an activity of one disintegration per second, or the equivalent of 27 pCi. Yet the radioactive fallout yield of even a "nominal" nuclear device is more easily expressed in megacuries—millions of curies of activity.

Measurement in curies does not, however, define the type or energy of the radiation being emitted. That information is specific to each radionuclide and is important to the evaluation of the risk created by exposure to curie, millicurie, or microcurie amounts of material.

F. Interactions of Radiation with Matter

Each type of radiation emitted by radioactive materials interacts with other matter in important yet distinct ways. Alpha particles carry an electrostatic charge of +2 units. When an α particle passes near another atom, the electrons in its orbital shells are as attracted to the α particle by virtue of their own negative (-) charge. Some electrons are merely excited by the event, i.e., they move from a lower to a higher energy state while remaining in orbit around the nucleus. For many others, however, the coulombic attractions of the α particles are too strong; these electrons are stripped away from their original atoms and travel freely for a time, leaving the mother atom in an ionized state. Balance of electric charges is soon restored, but in reaching neutrality, some atoms form new combinations with other atoms—new molecules are born. In many ways, an α particle can be visualized as a tiny, speedy electromagnet, sweeping free electrons into its path.

The electrostatic attraction is a mutual one; the electrons in nearby atoms are attracted by — and attract — the speeding α particles. The coulombic forces energize the electrons, pulling them away from atoms by giving them sufficient energy to escape. At the same time the electrons act as a drag on the α particle. Its energy is reduced by the amount that the electrons' energy is increased. According to fundamental physical law,[35] the energy is conserved, neither created or destroyed. The ionization that occurs in the path of an α particle represents a transfer of energy. The amount of energy transferred per unit of distance traveled by the α particle is known as a linear energy transfer (LET). See e.g.,

Committee on the Biological Effects of Ionizing Radiations, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980, at 13 (1980), DX-1025 (hereinafter cited as the "BEIR-III Report"). Alpha radiation is "high-LET" radiation; so many electrons are excited or ionized by α particles that a great deal of energy is transferred in a short distance. The range of an α particle traveling through matter thus tends to be fairly short. As soon as the α particle has transferred the bulk of its energy, it slows down sufficiently to capture two electrons of its own, becoming a neutral, inert helium atom.[36]

The range of an α particle depends largely upon the energy of the particles and the density of the medium through which it passes. Radioactive α-emitters shower their surroundings with particles having an energy between 0.1 MeV and 10 MeV. Such energies give the alpha radiation a range in air of less than 10 cm. The range in more dense material, for example paper, aluminum foil, or human cell tissue is far less, on the order of a few μm. The range of α particles, or conversely, the stopping power of material bombarded by them, is computed with good accuracy through a system of mathematical formulae not directly relevant here.[37] For the purposes of this case, the general range of α particle radiation, i.e., a few centimeters in air, a few microns (μm) in living tissue[38] is important information to use in assessing the risks presented by potential and actual exposure to α-emitting radionuclides.[39]

Beta particles (β-) interact with matter somewhat differently than α radiation. As a consequence of β- particles having far less mass than an α particle (M_β = 1/7360 M_α) and a negative rather than positive electric charge,[40] relatively low linear energy transfer (LET) takes place per unit of distance traveled. Beta particles are far more easily deflected by collisions with other electrons or nuclei, and cause ionization of atoms by colliding with other electrons or by passing near enough to repel electrons (having the same negative charge). Having a low LET factor, however, means that β- particles in the 100 Kv-2 MeV energy spectrum have significantly greater range and penetrating power than do α particles carrying even twice as much energy. They may traverse several meters in air at speeds approaching that of light. J. Cork, Radioactivity and Nuclear Physics 118 (1947). In cell tissue, β- particles may leave a trail of ionization several millimeters in length.

Beta particles, like other ionized electrons, also radiate energy in the form of gamma rays as they are deflected by nuclei and slow down, eventually returning to orbitals of other atoms. This "braking" radiation, called Bremsstrahlung, may in turn strike other electrons, exciting them into further ionizations.

Gamma radiation interacts with matter in several different ways: (1) photoelectric absorption; (2) Compton scattering; (3) pair production; (4) Rayleigh scattering; or, it may not interact at all, passing through the exposed material completely unimpeded. Since gamma rays have no electric charge, ionization by gamma radiation occurs only when a gamma ray strikes an orbital electron. If a gamma ray striking an electron is totally absorbed, the electron is stripped away from the atom, and possessed of the full energy of the gamma ray, careens through surrounding matter in a fashion very much akin to a β particle. Thousands of ionizations result. This "photoelectric" effect is the dominant form of interaction for gamma rays whose energy is less than 1.0 MeV.[41]

For gamma rays of greater energy (0.3-3 MeV), the phenomenon known as Compton scattering is predominant: a gamma ray striking an electron may only impart a portion of its energy to the particle. The ionized electron is driven in one direction, the gamma ray photon, now of lesser energy, is deflected on a new path. In Compton scattering, a gamma ray may thus ionize several electrons before its energy is wholly transferred.

For gamma rays of an energy of 1.02 MeV or greater another interaction may occur if the photon strikes a nucleus: the gamma ray can disappear, leaving a positron (β+) and an electron (β-) in its place. This phenomenon, known as pair production, ultimately generates further gamma radiation: when the positron comes in contact with another electron both particles are annihilated, yielding two gamma photons of an energy approximating 0.51 MeV each. These go on to ionize other electrons, or pass out of the irradiated material entirely. At energies above 10 MeV, pair production is the predominant interaction. See I F. Whicker & V. Shultz, Radioecology: Nuclear Energy and the Environment 51 (1982). Finally, gamma rays of low energy (<100 Kev) may experience Rayleigh scattering, the elastic deflection of the gamma

photon by an electron with no energy being transferred to the electron.

Gamma radiation by itself does no damage to exposed matter—if it passes through without collision.[42] When the gamma rays collide with electrons, as they may at any point along their path, ionizations occur just as if the matter had been bombarded with high energy beta particles. As we shall see, ionization of matter in living tissue may cause serious harm to the affected cells, and ultimately, the whole organism.

A fourth type of radiation emitted by nuclear explosion, free neutrons, also causes ionization in a somewhat indirect fashion. A neutron may be absorbed by a nucleus with which it collides, yielding a free proton, an α particle, another neutron, or a gamma ray. These charged particles and gamma rays interact with matter as previously described. Neutrons may also collide with nuclei and scatter them without being absorbed. Neutrons remaining in the free state decay into free protons and β- particles at a rate giving them a half-life of roughly 10.8 minutes:

$$_{0}^{1}n \longrightarrow {}_{1}^{1}p + {}_{\beta-} + \bar{\nu}$$

($\bar{\nu}$ is an antineutrino) H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 447, 498-500 (5th ed. 1972).[43]

While neutron interactions are a significant health concern in cases of direct exposure to a nuclear explosion or to a nuclear reactor, they are important to this case in only one respect: free neutrons from a nuclear explosion will interact with the surrounding air or with soil drawn up into the mushroom cloud, forming radioactive isotopes through absorption reactions. This additional activity adds to the radioactive burden of the fallout cloud, increasing the total risk of radiation exposure from the event. See Part III, infra.

G. The Mass-Energy Relationship

Mention has already been made of the Laws of Conservation of Mass and Energy—the concepts that in any chemical reaction the total mass of the system remains constant, and that in any physical interaction the total energy of the system remains constant. In an

absolute sense, neither matter nor energy is created or destroyed in any reaction. Yet an atomic bomb, a device containing only a few kilograms of metallic material yields energy—heat, light, and explosive force—in incredible amounts.

The key is found in a simple, fundamental relationship between matter and energy, a relationship which Albert Einstein originally defined and which most people have at some time seen expressed as

$$E = mc^2$$

E represents energy, expressed in ergs; m represents mass, expressed in grams; c is the speed of light, expressed in cm/second ($c = 2.9979250 \times 10^{10}$ cm sec^{-1}). Put together in the simplest terms, matter and energy are equivalent. Matter may be converted to energy by a factor of approximately 9×10^{20} ergs per gram. 49×10^{20} ergs, if released all at once, generate the explosive power of approximately 21.5 kilotons of TNT—more than either of the bombs dropped on Japan. Cf. S. Glasstone & P. Dolan, The Effects of Nuclear Weapons 13 & Table 1.45 (3d ed. 1977) DX-1242. A "nominal" yield nuclear device (approx. 20 kt TNT) derives its energy from the annihilation of a little less than one gram of matter.[45]

If $E = mc^2$, then $m = E/c^2$. Using this equation and a conversion factor factor (1 kt TNT equals 4.18×10^{19} ergs) then the quantity of matter consumed can be calculated:

$$m = \frac{(4.18 \times 10^{19} \text{ ergs})(20)}{(9 \times 10^{20} \text{ cm}^2/\text{sec}^2)}$$

$$m = 9.288 \times 10^{-1} \text{ grams, or } 0.9288 \text{ gm.}$$

Similarly, the energy released in radioactive decay can be precisely accounting for by finding the difference in mass between the mass of the original nuclide and the mass of the daughter nuclide and emitted particles. The decay products will be a tiny bit lighter.[46]

H. The Nuclear Fission Process

The discovery of radioactivity at the turn of the last century led quickly to further discoveries. The nature and properties of alpha, beta and gamma radiation were closely scrutinized. In 1920, physi-

cists predicted the existence of a new particle—the neutron—having roughly the same mass as a proton, but no electric charge. In 1932, experimental bombardment of beryllium metal with α particles yielded a new highly penetrating form of radiation that British physicist James Chadwick correctly identified as neutrons. By 1937, reports were published indicating that elements heavier than uranium could be synthesized through bombardment of uranium with neutrons.[47] By early 1939, Otto Hahn and Fritz Strassman published evidence that bombarding uranium with neutrons produces an unprecedented reaction: fission of the uranium nuclei into two lighter fragments.[48] It was soon determined that fission of uranium yielded two fragments of unequal mass, at least two additional free neutrons, and a shower of gamma rays and neutrinos. The atomic numbers (Z) of the two fragments add up to 92, the atomic number of uranium. The weights of the fission products and the three neutrons released by fission[49] add up to an amount slightly less than the mass of the uranium atom plus one neutron: a difference of approximately 0.18 amu.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow (^{236}_{92}U^{*}) \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + Q$$

where Q represents the energy released in this reaction. H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 510 (5th ed. 1972). Conversion of that mass difference to energy according to $E = mc^2$ gives an energy (Q) of nearly 175 MeV. The two fission products are both highly radioactive nuclides which soon decay to stable elements (^{141}Pr and ^{92}Zr), releasing 22 MeV of additional energy in the process. The sum of these energies is nearly 200 MeV per fission of ^{235}U—close to the energy value determined by theoretical calculation. See S. Glasstone, Sourcebook on Atomic Energy 390-393 (2d ed. 1958); H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 509-510 (5th ed. 1935); 3 E. Hyde, et al., The Nuclear Properties of the Heavy Elements: Fission Phenomena 5 (1971).

If gauged according to everyday human activity, 200 MeV is a small amount of energy, hardly noticeable. Yet at the atomic level, 200 MeV is enormous; even the radioactive decay of powerful α-emitters such as ^{226}Ra or ^{231}Pu barely releases 1/40 of the energy yielded per event by fission. Normal chemical processes, such as those involved in the combustion of fossil fuels, involve

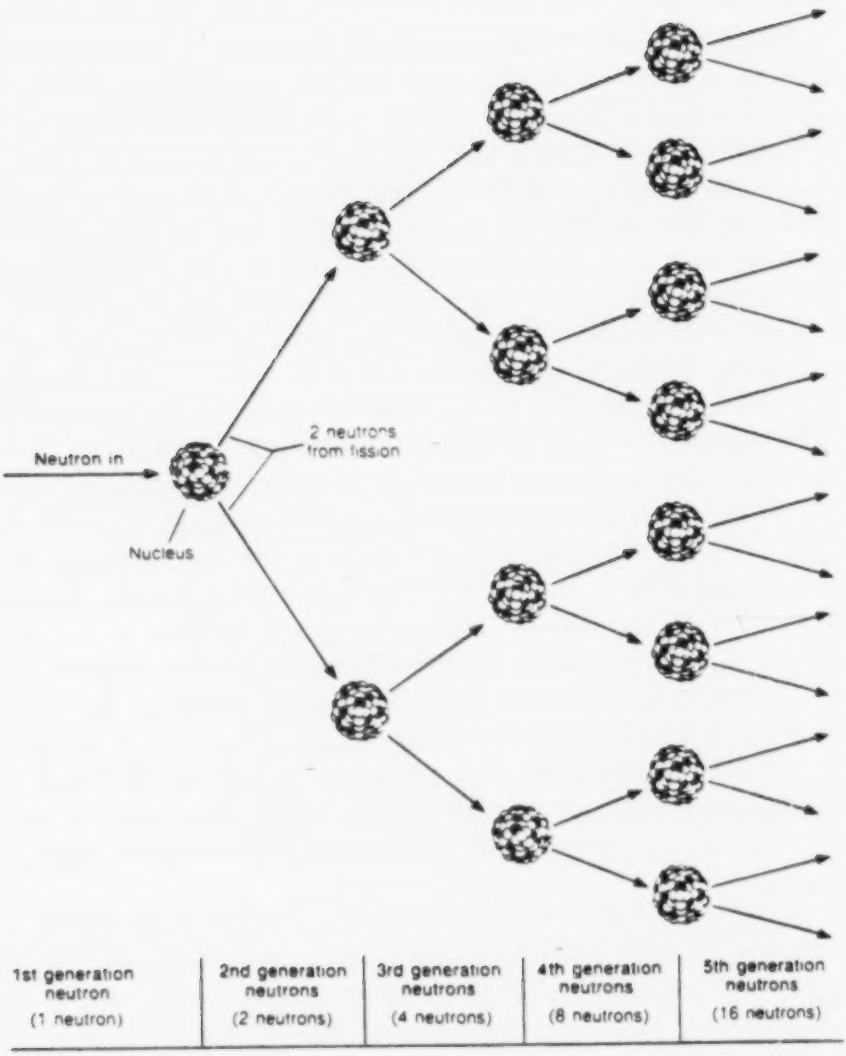


Figure 4. An expanding chain reaction, in which the number of neutrons doubles with every fission, from 1, 2, 4, 8, 16, 32 to trillions. The fission of some nuclei releases 3 neutrons, giving a tripling at each stage, from 1, 3, 9, 27, 81, 243, . . . to trillions of neutrons. Nuclear processes are so fast that the trillions of neutrons can be generated from one in less than a millionth of a second, giving a nuclear explosion.

From: J. Calvin Giddings, Chemistry, Man, and Environmental Change 425 (1973) [illustration by Alexis Kelner].

energies per atom on the order of a few eV, not MeV. See H. Semat & J. Albright, supra at 570.

The phenomenon of uranium fission generated great excitement from the moment of its discovery. Not only was fission a fascinating theoretical novelty once thought to be totally impossible, and not only did each fission of a uranium nucleus release dramatic quantities of energy, but the process offered a key to something much greater: couldn't the free neutrons released by one fission event be used to trigger two or three others? Scientists imagined a fission chain reaction in which each fission event leads to one or two more, ultimately yielding energy in practical, even explosive quantities. Assume, for example, that a chain reaction could be produced in which each fission of ^{235}U would lead to two more (2:1). See Fig. 4. While a single fission instantly yields nearly 180 MeV, or 3.2×10^{-11} joules of energy, a chain reaction growing at the 2:1 rate would produce after 40 generations nearly 1.1×10^{12} fission events,[50] yielding nearly 2×10^{14} MeV, or 32 joules—enough power to set a small light bulb aglow for a second or two. After 37 more generations, the total yield approaches 4.3×10^{12}J, or roughly the equivalent of 1 kiloton of TNT. Five additional generations would produce a total energy equivalent to 33 kt of TNT. Cf. S. Glasstone & P. Dolan, The Effects of Nuclear Weapons 13 (3d ed. 1977) DX-1242. Assuming a perfect 2:1 chain reaction, an explosive yield of 33 kilotons would require fission of 4.8×10^{24} atoms, or approximately 1,887 grams of ^{235}U—less than five pounds.

This amount is close to the actual mass of fissionable ^{235}U that would be consumed in a device of 33-kt yield. Under normal conditions, however, a 1.8 kg lump of ^{235}U will not be "critical," i.e., undergo a chain reaction that will result in an explosion. The actual "critical mass" of fissionable metals, whether ^{235}U, ^{239}Pu, ^{233}U or whatever, which will spontaneously produce such a reaction has been estimated to be in the range of 3-30 kg[51], depending on a number of factors. In smaller amounts, too many neutrons escape through the surface of the metal to sustain the reaction. A nuclear fission bomb, therefore, will contain a larger (subcritical) mass of fissionable material than is actually consumed in the subsequent fission reaction.

In a weapon, a "critical" or "supercritical" mass of ^{235}U may be achieved in one of two ways: (1) through violently forcing two subcritical quantities of metal together; or (2) by compressing a subcritical mass upon itself to the point that it becomes supercritical.

This second method, the implosion technique, is the far more efficient—and far more technically difficult—design. See also J. McPhee, The Curve of Binding Energy 75-95, 108-10 (1974).

The reaction would take place very quickly. Each generation would complete its fission in 0.01 microseconds (millionths of a second). An 82-generation chain reaction would take approximately 0.82 microseconds to complete. In fact, fission chain reactions in ^{235}U can proceed more rapidly; on the average, ^{235}U fission releases 2.5 neutrons per event, permitting a chain reaction of greater than the 2^x rate. Glasstone reports that one kiloton of TNT equivalence can be reached by the 51st generation.[52] 58 generations would yield roughly 100 kiloton TNT equivalence.

> It is seen, therefore, that 99.9 percent of the energy of a 100-kiloton fission explosion is released during the last 7 generations, that is, in a period of roughly 0.07 microseconds. Clearly most of the fission energy is released in an extremely short time period. The same conclusion is reached for any value of the fission explosion energy.

S. Glasstone & P. Dolan, The Effects of Nuclear Weapons § 1.57 at 17 (3d ed. 1977), DX-1242. Thus, for a 100-kiloton 235_U bomb, the chain reaction starts and ends in 0.58 microseconds, the last 0.08 microseconds of that process determining the gross energy yield of the fission device.[53]

The time-scale of a nuclear chain-reaction explosion is not merely curious atomic trivia. The energy yield in the last 0.1 microsecond of fission is a critical factor determining weapons design, as are considerations such as rate of neutron escape per "generation." As a fission reaction proceeds, the tremendous release of nuclear energy creates immense heat and pressure; the temperature at the core of the mass of uranium or plutonium

reaches millions of degrees Celsius by the 51st fission "generation."[54] Intense heat causes intense pressure, forcing the mass apart violently. To achieve maximum explosive yield, the device—by now a superheated mass—must somehow hold together long enough for the next seven or eight generations of fission to take place. Consequently, nuclear weapons designers have worked on ways of encasing the fissionable portion of a device in a "tamper," a shell of heavy material which by mere inertia[55] will hold the mass together for the crucial 0.07-0.08 microseconds. Using tamper material that will also reflect neutrons serves two purposes: (1) containment of the fissionable material long enough to achieve high yield; and (2) increasing the number of free neutrons available for fission by reducing the rate of neutron escape from the reacting mass. Uranium-238, for example, proves useful for this purpose.[56]

The testing of various materials as tampers for neutron reflectors was among the many purposes of the series of open-air detonations at the Nevada Test Site. The value, for example, of beryllium as a neutron reflector might be one of many technical questions answered by a specific test.[57] This type of testing has varying impact on the radioactive fallout burden in surrounding areas; use of a heavy tamper of ^{238}U leaves far higher quantities of plutonium in the fallout cloud than does the fission process itself. The ^{238}U in the shell, bombarded with neutrons from the chain reaction and vaporized by its heat, is converted in significant part to ^{239}Pu by this reaction:

$$^{238}_{92}U + {}^{1}_{0}n \longrightarrow (^{239}_{92}U^{*}) \longrightarrow {}^{239}_{93}Np \longrightarrow {}^{239}_{94}Pu$$

Some unreacted ^{238}U would remain as well. If the neutrons emitted by the bomb's initial processes are of sufficient energy, ^{238}U will itself undergo fission, adding to the energy of the explosion and to the quantity of highly radioactive fission products in its fallout.

The greater time-scale permitted by use of efficient tamper/reflector material as well as improved design technique is indispensable to another process: the nuclear fusion reaction of a hydrogen bomb.

I. The Hydrogen Bomb

The reality of the fission bomb in turn opened the door to the possibility of a device utilizing the nuclear processes of the sun and stars, nuclear fusion, to achieve energy yields in the megaton range.[58] Rather than splitting heavy atoms to produce energy, fusion binds the lightest elements together into new atoms. At the core of the sun, temperatures range into the millions of degrees, Celsius. In that heat, the nuclei of hydrogen atoms develop energies greater than 100 kev, permitting a number of reactions to occur:

(1) ${}_1^1H + {}_1^1H \longrightarrow {}_1^2H + {}_{\beta^+} + 1.4$ MeV
(2) ${}_1^2H + {}_1^2H \longrightarrow {}_1^3H + {}_1^1H + 4.03$ MeV
(3) ${}_1^2H + {}_1^2H \longrightarrow {}_2^3He + {}_0^1n + 3.27$ MeV
(4) ${}_1^2H + {}_1^1H \longrightarrow {}_2^3He + {}_\gamma + 5$ MeV
(5) ${}_1^2H + {}_1^3H \longrightarrow {}_2^4He + {}_0^1n + 17.06$ MeV
(6) ${}_1^2H + {}_2^3He \longrightarrow {}_2^4He + {}_1^1H + 18.4$ MeV
(7) ${}_2^3He + {}_2^3He \longrightarrow {}_2^4He + 2{}_1^1H + 13$ MeV
(8) ${}_1^3H + {}_1^3H \longrightarrow {}_2^4He + 2{}_0^1n + 11.3$ MeV

The end result is the conversion of hydrogen to helium with the release of significant energy:

$$4{}_1^1H \longrightarrow {}_2^4He + 2_{\beta^+} + {}_\gamma + 26.7 \text{ MeV}$$

S. Glasstone, Sourcebook on Atomic Energy 442-443 (2d ed. 1958).[59] The reactions proceed at widely varying rates; fusion of two ^1H nuclei at the core of the sun, for example, takes between 10^9 and 10^{11} years.

Fusion reactions of the heavy isotopes of hydrogen, in contrast, take between 1 and 30 microseconds at a temperature of 20 million degrees Celsius. These reactions were of interest to those who sought to develop the hydrogen bomb. The temperatures in the core of a fission explosion approach those found in the sun and other stars, even if only for a time period of about 1 microsecond. Development of a hydrogen bomb, therefore, required development of a nuclear fission "trigger" that could create temperatures in the 20 million to 200 million degree range and maintain them long enough to initiate nuclear fusion reactions using tritium (^3H and deuterium (^2H). This in turn would ignite additional deu-

terium-deuterium reactions, or might utilize the a lithium reaction

$$^{6}_{3}Li + ^{1}_{0}n \longrightarrow ^{4}_{2}He + ^{3}_{1}H + 4.8\ MeV$$

to generate more tritium-deuterium fusion.[60] At 200 million degrees Celsius a deuterium-tritium mixture will "ignite: in as little as 0.28 microseconds (compared to a reaction time of roughly 4.8 microseconds to ignite deuterium fusion by itself), see e.g., W. Lawrence, The Hell Bomb 41, 46 (1950), with an energy yield per reaction of 17.6 MeV, compared to 3.2 or 4.0 MeV. See S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 1.69 at 21 (3d ed. 1977) DX-1242. Pound for pound, heavy hydrogen will yield 1.5 to 4 times as much energy through fusion than does uranium or plutonium in a fission device. Using a large amount of deuterium fuel, a thermonuclear explosion can produce energy in the range approaching 100 megatons of TNT.[61]

A number of the tests in the 1950's at the Nevada Test Site were directly related to development of a suitable fission bomb "trigger" device for producing a hydrogen fusion explosion. Actual tests of fusion-based, or thermonuclear, bombs took place in the United States Pacific Test Range in the Marshall Islands, but preliminary work was done on an expedited basis at NTS in reaction to fears concerning rapid weapons development by the U.S.S.R.[62] See e.g., "AEC Test Program," AEC 388/1 (Dec. 24, 1950, DX-82; "AEC Pre-Greenhouse Test Program," AEC 388/3 [Ranger Series] (Jan. 5, 1951) DX-83.[63]

Development of the "super", as the hydrogen bomb was then called, was one goal behind establishment of the NTS; improvement of fission weapons in an atmosphere of national emergency caused by events in Korea was another. See 2 R. Hewlett & F. Duncan, Atomic Shield: A History of the United States Energy Commission 535 (1969), DX-1002; Nevada Test Org., "Background information on Nevada Nuclear Tests" (May 1, 1957), PX- 245.[64]

III. NUCLEAR FALLOUT

A. Nature of Fallout Radioactivity

The processes of nuclear fission and nuclear fusion release tre-

mendous amounts of energy as predicted by Einstein's postulate $E = mc^2$. Both processes directly produce reaction products, gamma radiation and free neutrons of significant energy. Many of the gamma rays are absorbed by air surrounding the bomb which along with the reactants themselves, generate tremendous amounts of heat. A luminous "fireball" forms around the exploding device within the first second following detonation, glowing at many times the apparent brightness of the sun.[65] The fireball quickly expands outward as a toroidal (i.e., doughnut-shaped) cloud of superheated material, drawing great amounts of cooler air up into the familiar "mushroom" cloud associated with atomic explosions. See Fig. 5.

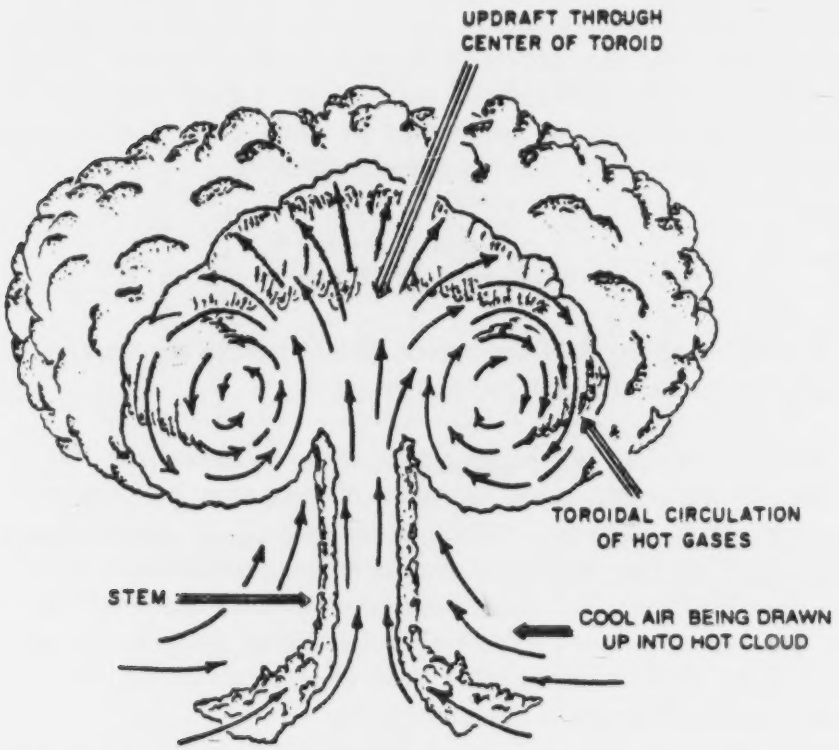


Fig. 5. Cutaway showing artist's conception of toroidal circulation within the radioactive cloud from a nuclear explosion.

For those who are exposed directly to the explosion of a fission or thermonuclear device, the heat, the blast, the gamma and neutron radiation pose serious and often lethal risks of injury.[66] See

Comm. for the Compilation of Materials on Damage Caused by the Atomic Bombs. . . . , Hiroshima and Nagasaki: The Physical, Medical, and Social Effects of the Atomic Bombings 105-334 (pap. ed. 1981) [hereinafter cited as "Hiroshima and Nagasaki"]. The plaintiffs in this action, however, do not allege direct exposure to atomic blast effects. Instead they are concerned with exposure to the residual radiation present in the smoky ashes of the fireball.

The residual radioactivity of an atomic explosion—the material which becomes "fallout"—is derived from three sources: (1) fission products, i.e., the nuclear fragments resulting from the splitting of uranium or plutonium nuclei; (2) unused nuclear fuel (esp. plutonium), and (3) induced activity, i.e., radionuclides generated by bombarding stable elements in the bomb materials, air, tower metal, soil, seawater, etc. with neutrons. Any detonation of a nuclear device produces residual radioactivity in these three ways. The amount of material contributed by each process, however, varies with the specific qualities of each explosion.

(1) Fission Products

The direct products of the nuclear fission process are the most important source of fallout radioactivity.

Neither uranium nor plutonium split into standardized fragments; fission results in the formation of more than 200 different isotopes of 36 elements, ranging from zinc (Z = 30) to dysprosium (Z = 66). The most common fission products have mass numbers of 95 and 139; those with mass numbers approximating 117, representing fission into nearly equal halves, comprise 1% or less of the total. Yield of other products grouped in relation to mass number is generally illustrated in Fig. 6.

Both uranium and plutonium have a significantly greater number of neutrons than protons. See Table 4.

This imbalance is carried on into the fission products, which usually have more neutrons than do the naturally occurring isotopes of the same elements.[67] Consequently, all but a few of the fission

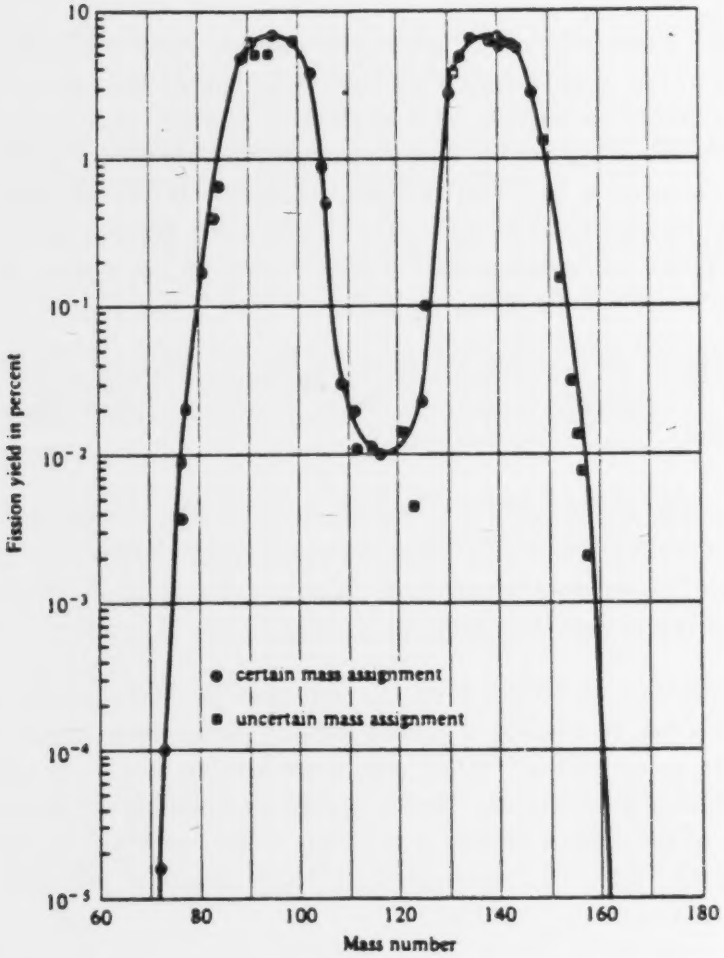


Figure 6. Graph showing yields of fission product chains of ^{235}U as a function of mass number. [After "Plutonium Project Report on Nuclei Formed in Fission," *Revs. Modern Phys.*, 18, 539, (1946).]

TABLE 4

isotope	protons	neutrons	n/p
^{233}U	92	141	1.532
^{235}U	92	143	1.554
^{238}U	92	146	1.5869
^{239}U	94	145	1.542

product radionuclides are extremely unstable—and highly radioactive. They seek stability through emission of beta particles, which shifts the nuclear ratio in favor of protons. Many also release excess energy in the form of gamma radiation. Most products must undergo a series of β-decay transitions before reaching a stable, or nearly stable ratio of particles. The characteristics of each product's series, called a decay chain, is important to a determination of the total yield of fission products.

Consider, for example, the fission product krypton-95: it experiences six β-decay transitions before reaching a stable nuclide (half-lives are given in parentheses):

$$^{95}_{36}\text{Kr} \xrightarrow{\beta} ^{95}_{37}\text{Rb} \xrightarrow{\beta} ^{95}_{38}\text{Sr} \xrightarrow{\beta} ^{95}_{39}\text{Y} \xrightarrow{\beta}$$

(very short) (<2.5 sec.) (48 sec.) (10.9 min.)

$$^{95}_{40}\text{Zr} \xrightarrow{\beta} ^{95}_{41}\text{Nb} \xrightarrow{\beta} ^{95}_{42}\text{Mo}$$

(65 days) (35 days) (stable)

The n/p ratio of ^{95}Kr is 1.63; the n/p ratio for ^{95}Mo is 1.26, far closer to parity, lending it greater stability. Some decay chains are as long (e.g., ^{90}Br or ^{144}Xe); others are notably shorter. A select few fission products are "born" stable, contributing no radioactivity to the fallout clouds (e.g., ^{96}Zr, ^{152}Sm, or ^{86}Kr). A fairly complete listing of fission product decay chains is provided in Appendix A of this opinion.

While the existence (or nonexistence) of ^{95}Kr in the fireball of a nuclear explosion or the core of a nuclear reactor is a curious theoretical novelty, it is not by itself very significant. Overall review of the properties of all known fission products, however, disclose important general characteristics of fission product activity:

1. fission products, if radioactive, emit β- particles an average of 3 times before reaching stability;

2. many fission products also emit gamma rays;

3. the half-lives of most fission products and "daughter" nuclides in the decay chains are very short when compared

to naturally occurring nuclides such as ^{238}U or even ^{226}Ra: and

4. the chemical and physical properties of fallout will change as radioactive decay proceeds down the chains.

From these generalizations, we may infer that the explosion of a fission device produces an intensely radioactive cloud of fallout which releases tremendous beta and gamma radiation in the first few hours and which declines at a rapid rate until only the longer-lived radionuclides and stable isotopes remain. These inferences are borne out by the experimental evidence derived from atomic testing.[68]

A "Nominal" 20-kiloton fission bomb releases a massive quantity of radioactivity into the environment. Less than two kilograms of fission products yield activity more easily measured in mega curies—millions of curies, even if only gamma radiation is considered. See Table 5.

TABLE 5

T	γ activity
1 min.	820.000 MCi
5 min.	120.000 MCi
1 hr.	6.000 MCi
1 day	133 MCi
1 wk.	13 MCi
1 mo.	2.3 MCi
1 yr.	0.11 MCi
10 yr.	0.08 MCi
100 yr.	0.006 MCi

Table 5. T represents the elapsed time since detonation of the 20-kt fission device. [source: U. S. Atomic Energy Comm., Assuring Public Safety in Continental Weapons Tests 91 n. 6 (1953), PX-740.]

Glasstone and others report that for gamma rays, the fission product radioactivity at t seconds following detonation of a "nominal" 20-kt bomb may be estimated according to the formula:

$$A_\gamma \text{ (in Mci)} = \frac{4.1 \times 10^{24}(t^{-1.2}) \text{ d sec}^{-1}}{3.7 \times 10^{16} \text{ sec}^{-1}}$$

Further, "[t]he rate of emission of beta particles from the fission products is roughly twice that of gamma-ray photons; hence at a time t sec. after detonation:"

$$A_\beta \text{ (in Mci)} = \frac{8.2 \times 10^{24}(t^{-1.2}) \text{ d sec}^{-1}}{3.7 \times 10^{16} \text{ d sec}^{-1}}$$

S. Glasstone, ed., The Effects of Atomic Weapons ¶ 8.11-8.12 at 251 (1950), PX-690/DX-470; see also K. Way & E. Wigner, "The Rate of Decay of Fission Products," 73 Phys. Rev. 1318 (1948). Using the latter formula, a table similar to Table 5 may be prepared reflecting fission product beta activity:

TABLE 6

T	β- activity
1 sec.	2.2 × 108 MCi
1 min.	1.6 × 106 MCi
5 min.	234,000 MCi
1 hr.	11,881 MCi
1 day	262 MCi
1 wk.	25 MCi
1 mo.	4.33 MCi
1 yr.	0.22 MCi
10 yr.	0.0139 MCi
100 yr.	0.000878 MCi

Table 6. T represents elapsed time since detonation of 20 kt fission device.

Assigning an average energy of 0.4 MeV to the beta particles emitted by fission products,[69] quick calculation discloses an overall energy of equal or greater magnitude than that radiated as gamma rays:

$$(3.3 \times 10^{24})(t^{-1.2}) \text{ MeV sec}^{-1}$$

However, the potential risks of exposure to beta radiation were sometimes discounted because of the particles' much shorter range. But see e.g., A. Broido & Teresi, "Tolerance in Man to External Beta Radiation," USNRDL Tech. Memo. No. 4 (Aug. 6, 1954), PX-565, "Analysis of Hazards Associated with Radioactive Fallout Material," 5 Health Physics 63-9 (1961), PX-563; AEC Symposium, "The Shorter-Term Biological Hazards of a Fallout Field," 126-160 (Dec. 1956) PX-699/DX-641; Part VIII, infra.

Fission product radioactivity, even if evaluated only in terms of gamma radiation, can yield tremendous rates of radiation exposure: for example, if the fission products from a one-kiloton explosion (a quantity of material not larger than 58 grams, or about 2 ounces) were spread uniformly over a smooth plane one square mile in area, the rate of radiation exposure at a height of three feet off the ground at one hour after detonation would be nearly 2,800 rads/hr.—far more than the acute lethal dose for human beings. S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 9.159 at 454 (3d ed. 1977), PX-1242; see infra at Part IV. Ounce for ounce, radioactive isotopes are the most toxic materials known to man. J. C. Giddings, Chemistry, Man & Environmental Change 412 (1973). And they are inevitably the product of detonation of a nuclear weapon, because every weapon tested so far has used fission of uranium or plutonium as the source of at least part of its tremendous explosive power. All nuclear devices tested in the atmosphere have produced some quantity of highly radioactive fission products that return to the surface as "fallout".

Fortunately, the rate of fission product activity declines very rapidly as indicated by the tables and equations, supra, and by Fig. 7.

The curve indicated by Fig. 7 represents the radioactivity of fission products over a period of time as decreasing according to the relationship:

$$R_t \approx R_1 t^{-1.2}$$

where R_t is the dose rate at time t and R_1 dose rate at unit time. Glasstone & Dolan, supra ¶¶ at 9.146—9.153, at 450-52. This rate of decay has important implications for the monitoring of fallout activity and the assessment risks posed by exposure to fallout. See Part III (D); Part VIII, infra.

(2) Residual Uranium and Plutonium

To produce a "nominal" 20 kt nuclear explosion, the complete fission of approximately 1,200 grams of ^{235}U or ^{239}Pu is required. The "critical mass" of fissionable material, the minimum amount that makes such a chain reaction possible, is significantly larger:

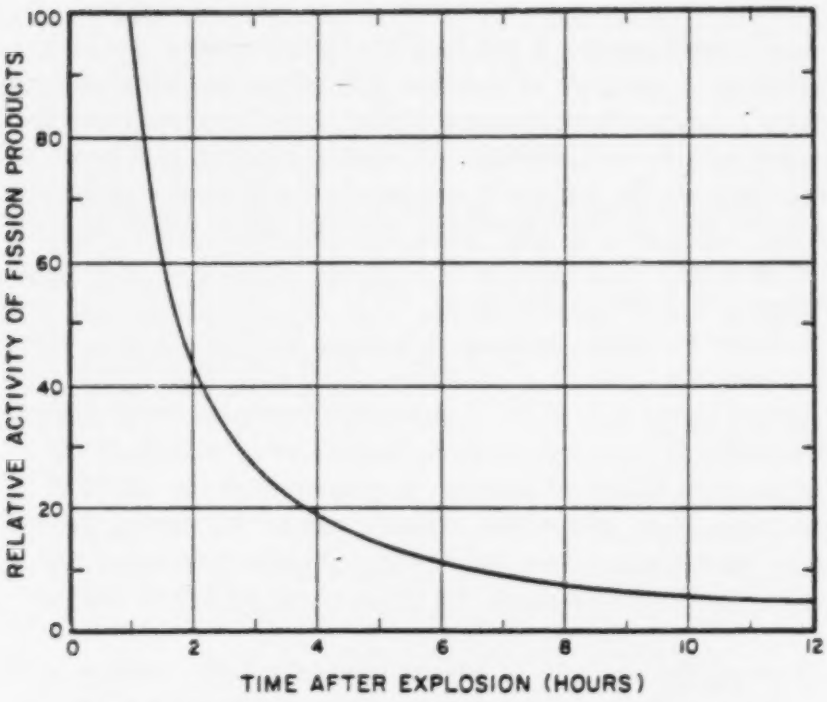


Figure 7. Rate of Decay of fission products after a nuclear explosion (activity is taken as 100 at 1 hour after the detonation).

approximately 3 kg. for ^{239}Pu and roughly 10 kg. for ^{235}U, depending upon shape. See J. C. Giddings, Chemistry, Man and Environmental Change 432 (1973). Most of the fissionable "fuel" of an atomic bomb thus remains unused by the fission process. Vaporized by the intense heat of the fireball, the remaining ^{235}U or ^{239}Pu becomes a part of the radioactive fallout cloud. Similar residues may likely be present as a result of the use of ^{238}U as a component material of the bomb. Free neutrons produced by the fission process can produce plutonium from uranium-238 by the following processes:

$$^{238}_{92}U + {}^{1}_{0}n \longrightarrow {}^{239}_{92}U^{*} \xrightarrow{\beta} {}^{239}_{93}Np \xrightarrow{\beta} {}^{239}_{94}Pu$$

$T_{1/2}$ = 2.35 min. 2.35 d. 24,400 yr.

Further, the abundance of high-energy neutrons present in the fireball of a thermonuclear explosion may interact with uranium-235 and uranium-238 to produce a variety of isotopes of plutonium (e.g., ^{238}Pu, ^{240}Pu, ^{241}Pu) and heavier nuclides such as Americium (^{241}Am) and Curium (^{242}Cm).[70] In fact, the heavy element

einsteinium (^{253}Es) was first identified in the debris from the explosion of the first H-bomb in the Pacific in 1952. C. R. Hammond, "The Elements," in Handbook of Chemistry and Physics, at B-12 (64th ed. Weast 1983).

Plutonium will always be present in fallout from nuclear detonations. According to the UNSCEAR Report, 90% of the plutonium now dispersed in the environment came from tests carried out prior to 1963; by 1973 an estimated 320 kCi of ^{239}Pu and ^{240}Pu and another 26 kCi of ^{238}Pu had been so dispersed. UNSCEAR Report (1977), Px-706/DX-605, at 148.[71] Converting from kilocuries of ^{239}Pu activity to actual mass of the heavy metal we can estimate that nearly 5 metric tons[72] of plutonium have been dispersed by fallout.[73]

While a "nominal" fission detonation may produce many fission products in gram (or milligram) amounts, plutonium is dispersed in kilogram quantities. Yet plutonium contributes less to fallout activity because it is less radioactive than most fission products; its half-life of 24,400 years (^{239}Pu is far longer than most fallout components. The 0.06 curies of radioactivity produced by 1 gram of plutonium-239 is far less than that of cesium-137, or iodine-131, or other important fission products:

nuclide	half-life	Specific Activity (Ci/gm)
^{239}Pu	24,400 yrs	0.06
^{137}Cs	30.28 yrs	86.1
^{90}Sr	28.1 yrs	141.0
^{131}I	8 days	1.24×10^5

Plutonium, of course, persists for a much longer period; 99% of the iodine-131 produced in open air testing has long since decayed, while 99+% of the plutonium ever dispersed in the environment still remains.[74] Plutonium, uranium and other heavy element residues represent a significant long-term component of nuclear fallout. In fact, "in the period from 20 hours to 2 weeks after the burst, depending to some extent upon the weapon materials, those isotopes can contribute up to 40% of the total activity of the weapon debris." S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 9.32 at 405 (3d ed. 1977).

(3) Induced Activity

The tremendous flux of free neutrons present in the fireball of a nuclear detonation themselves create radioactive residues of significance to radioactive fallout.

It was discovered early that free neutrons colliding with the nuclei of atoms could react, perhaps merely by joining the nucleus and forming a new isotope of the element, or perhaps by joining the nucleus and ejecting other particles in the process, transforming the nuclide's identity. For example, nitrogen reacts with free neutrons to form Carbon-14, an important radionuclide:

$$^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{14}_{6}C + ^{1}_{1}H + Q$$

Carbon-14 is a β-emitter with a half-life of 5730 years. As noted above, neutrons can react with light nuclides such as lithium-6, breaking them apart:

$$^{6}_{3}Li + ^{1}_{0}n \longrightarrow (^{7}_{3}Li^{*}) \longrightarrow ^{3}_{1}H + ^{4}_{2}He$$

Or, neutrons may add to the mass of sodium nuclei, rendering them unstable and radioactive:

$$^{23}_{11}Na\ ^{1}_{0}n \longrightarrow ^{24}_{11}Na$$

Sodium-24 is a β-emitter with a half-life of 15.0 hours:

$$^{24}_{11}Na \longrightarrow ^{24}_{12}Mg\ (\text{stable}) + _{\beta-} + _{\gamma}$$

This type of transformation, or activation, of nuclei by free neutrons occurs with many elements in the atmosphere, soil or sea which are directly exposed to the nuclear fireball. Sodium-24, silicon-31, manganese-56 and other nuclides may be produced in significant quantities.

The non-explosive components of the device itself, or the steel tower on which it may have rested before detonation, may also be an important source of induced radioactivity; neutron-capture reactions generate radioactive isotopes of iron, copper, zinc, manganese and cobalt, as well as aluminum, although the radioactive form of the latter, aluminum-28, has a very short half-life, about 2.3 minutes. S. Glasstone & P. Dolan, supra, at 405-407.

A number of factors influence the role which induced radioactivity plays in determining the nature of fallout radiation. Fire-

balls detonated on or near the surface can interact with many thousands of tons of surface material, while a detonation high in the atmosphere draws very little soil or seawater into its billowing clouds of explosion residues, reacting only with surrounding mass of air. The design of test explosions at the NTS reflects in part a recognition of this problem: often devices were exploded at a height above the surface greater than the estimated radius of the initial fireball. The shock wave would press downward on the surface at all points, hopefully minimizing the amount of soil and dust drawn into the cloud itself.

Induced activity can be a significant source of fallout radioactivity in a surface detonation. See Table 7.

TABLE 7. Approximate yields of several important activation radionuclides per megaton of fission.

radionuclide	half-life	yield (in MCi)
$^{3}_{1}H$	12.5 years	< 1
$^{14}_{6}C$	5600 years	3.4×10^{4}
$^{39}_{18}Ar$	260 years	59
$^{24}_{11}Na$	15 hours	2.8×10^{11}
$^{32}_{15}P$	14 days	1.9×10^{8}
$^{42}_{19}K$	12 hours	3×10^{10}
$^{45}_{20}Ca$	52 days	4.7×10^{7}
$^{56}_{25}Mn$	16 hours	3.4×10^{11}
$^{55}_{26}Fe$	2.9 years	1.7×10^{7}
$^{59}_{26}Fe$	46 days	2.2×10^{6}

1. F. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment 107 (1982) and sources cited therein.

Comparison of these figures with fission product yield estimates (e.g., 125 MCi of ^{131}I per megaton of fission) plainly demonstrates that induced activity is a significant variable affecting total fallout radioactivity and its characteristics. And unlike fission products, induced activity fallout is not produced in neatly predictable amounts and proportions. Reference to the yield curve in Fig. 7 thus does not adequately index fallout activity due to activation products.[75]

B. Isotopes and Environmental Impact

Because of their rapid rate of decay, some of the fission and activation products of a nuclear explosion are of minimal importance to assessment of the risks of injury posed by fallout. They die too quickly. Isotopes such as iodine-136, with its 83 second half-life, have all but vanished within minutes after detonation, long before the hot gases and dust of the mushroom cloud could reach offsite communities. Other isotopes, such as 8-day iodine-131, or 30-year cesium-137, have come to be recognized as posing serious risks of injury to the downwind environment.

Furthermore, the chemical properties of fallout radionuclides affect their hazard potential. Isotopes such as krypton-85 ($T_{1/2}$ = 10.5 yrs.) or xenon-135 ($T_{1/2}$ = 9.2 hours) are inert gases by nature; they don't react with other chemicals, and they literally do not "fall out." Other products such as strontium-90 ($T_{1/2}$ = 28.5 years) or plutonium-239 ($T_{1/2}$ = 24,400 years) settle as dust on foodstuffs and upon ingestion, are absorbed into bone tissue, where they bombard sensitive marrow tissue with ionizing particles. The hazard presented by each component isotope of the fallout cloud is thus a product of both nuclear and chemical factors.

The nuclides that are of interest to our inquiry are identified according to a number of factors such as (1) total yield; (2) half-life; (3) radiation energies; (4) refractory or volatile qualities; (5) chemical characteristics; (6) uptake and concentration in the food chain; (7) degree to which the nuclide is retained in the body; and (8) concentration of the nuclide in sensitive tissue.

The refractory (i.e., heat resistant) qualities of a given isotope, for example, are an important factor determining whether it will be found mainly in the early fallout at the site of the explosion, or whether it will escape in the cloud of hot gases and debris that becomes "delayed" fallout affecting offsite communities. The fallout yield of any nuclear device experiences fractionation, the uneven distribution of radioactive products in early and delayed fallout debris:

> The phenomenon of fractionation is due to both chemical and physical separation of the radionuclides. Chemical separation occurs in the first few minutes. At zero time, every-

thing in the vicinity of the device is vaporized. As the fireball cools to about 3000°C the FeO [iron oxide] and soil components form liquid droplets in which the refractory elements dissolve. The fireball cools to the melting point of soil and iron oxides to 1500°C in about 20 sec. . . . The solidified droplets contain the refractory elements, while the volatile elements and their radioactive daughters remain in the gas phase. In 6-8 min., when the cloud has cooled to ambient temperature, -50°C, the volatile elements (except for Kr and Xe) and their daughters condense. . . .

H. Hicks, "Calculation of the Concentration of Any Radionuclide Deposited on the Ground by Offsite Fallout from a Nuclear Detonation," 42 Health Physics 585, 586 (1982), DX-1162. (citations omitted). Hicks lists elements important to fallout in two categories:

Volatile at 1500°C [in gaseous state]	Refractory at 1500°C [condensed as liquid or solid]
Germanium	Beryllium
Arsenic	Sodium
Selenium	Manganese
Bromine	Iron
Krypton	Cobalt
Rubidium	Copper
Molybdenum	Strontium
Technetium	Yttrium
Ruthenium	Zirconium
Rhodium	Niobium
Rhenium	Barium
Palladium	Lanthanum
Silver	Cerium
Cadmium	Praseodymium
Indium	Neodymium
Tin	Promethium
Antimony	Samarium
Tellurium	Thorium
Iodine	Uranium
Xenon	Neptunium
Cesium	Plutonium
Tungston	Americium
Gold	Curium
Lead	

See id. at 598, app. I. Elements in the "refractory" column will predominate in early fallout debris; those in the "volatile" column will more likely be found in delayed fallout residues. See also Appendix D, infra.

A number of variables affect how efficiently the fractionation process separates nuclides of the two categories as the fallout cloud develops. For example, strontium-90, a refractory isotope produced in significant quantities by fission explosions, does not condense in the initial refractory particles because it does not yet exist in quantity. Strontium-90 is produced primarily as a "daughter" isotope of the volatile elements krypton and rubidium:

$$^{90}_{35}\mathrm{Br} \xrightarrow{\beta} {}^{90}_{36}\mathrm{Kr} \xrightarrow{\beta} {}^{90}_{37}\mathrm{Rb} \xrightarrow{\beta} {}^{90}_{38}\mathrm{Sr}$$

(short) (33 sec.) (2.7 min.) (28 yrs.)

See Appendix A. Within 20 seconds of rapid cooling as described by Hicks, less than half of the krypton-90 has decayed into rubidium-90, and only a tiny fraction of that amount has decayed into strontium. Achieving a 90+% yield of strontium-90 through rubidium decay takes longer than 10 minutes, longer than it takes much of the fallout cloud to cool to ambient temperatures. Thus strontium-90, a "refractory" isotope, will more likely condense as many "volatile" elements do, simply because of the timing involved. It becomes an important constituent of delayed fallout, which reaches downwind and global communities. Its long half-life (28.1 years), its close chemical similarity to the key nutrient calcium, the moderate solubility of its compounds and its tendency to concentrate in bone tissue, where it bombards sensitive marrow cells with high-energy beta particles, underscores its significance as a radioactive contaminant.

Where external exposure to fallout is of concern, the pathway to man is a simple one: direct contact with fallout materials in one's immediate surroundings. Fallout particles may come to rest upon skin or clothing, on houses or automobiles or other nearby surfaces, or fallout—particularly the tiniest particles—may be inhaled, a direct pathway resulting in internal exposure. See e.g., Brodsky, "Criteria for Acute Exposure to Mixed Fission Product Aerosols," 11 Health Physics 1017-32 (1965), PX-1045; G. Taplin, et al., "Evaluation of the Acute Inhalation Hazard from Radioactive Fallout Materials," Operation Teapot, WT-1172 (Feb. 1958), DX-359.

Internal exposure is the product of a number of environmental processes. Besides direct inhalation, fallout particles may fall on fruits and vegetables in the garden, or on foodstuffs exposed to the air, where they may be ingested unless carefully washed away. Fallout may be deposited on open fields and rangeland where it is ingested by livestock. A portion of the ingested fallout will be absorbed by the animals who may pass it on to people through meat or milk products.

Fallout reaching the soil may in turn be absorbed by the root systems of plants which may be eaten by people or by livestock who eventually pass it on to people. A fraction of fallout may find its way into the water supply; persons receive additional exposure by drinking the contaminated water, or by eating fish whose bodies have absorbed and concentrated the fallout radionuclide contaminating their aquatic environment.

Calculation of internal radiation exposure from these various sources is a complicated process that is fraught with tremendous uncertainty. Overlooking a single pathway can easily render analysis of internal exposure largely ineffective. For example, in a 1953 publication of the U.S. Atomic Energy Commission entitled Assuring Public Safety in Continental Weapons Tests, reported:

> Uptake by Animals. Cattle and other animals may eat plants which contain radioactive materials from fallout. Studies have been made of the possibility of hazard to humans as a result of eating meat from such animals. These studies indicate that the bone-seeking radioisotopes are of the greatest potential concern, and that the chief among these is radiostrontium.
>
> Cattle absorb 25 to 30 percent of the ingested strontium, with about 25 percent reaching the bone. A few days after entrance of radiostrontium into the body, about 99 percent of the remaining amount will be in the bones. The only potential hazard to human beings would be the ingestion of bone splinters which might be intermingled with muscle tissue during butchering and cutting of the meat. An insignificant amount would enter the human body in this fashion.

Id. Px-740, at 122 (emphasis added). If one evaluates internal exposure solely in terms of strontium-90 ingested from meat and fish, the UNSCEAR Report (1977) confirms that at least in two strontium-90 studies, "[m]eat, fish and eggs contribute only to a small extent." Id. PX-706/DX-605, at 130. However, to say that bone splinters present the only hazard to human beings is patently absurd: no mention at all is made of milk and dairy products, the major pathway of strontium-90, iodine-131 and other radionuclides received from animal products. The UNSCEAR Report (1977) informs us that "In general, it may be said that ^{90}Sr in the diet comes mainly from milk products, grain products, fruit and vegetables," id. at 130, with milk products contributing about 30 percent of the strontium-90 transfer from food in the areas studied. The dairy products pathway is doubly important; not only does milk carry far more strontium-90 than the occasional bone bit in a hamburger, it is consumed more often by children, whose growing bones more readily absorb dietary strontium and who are more susceptible to radiation injury than are adults. See e.g., "Strontium-90 Concentrations on the Surface, in Milk, and in Bone for 1963. . . ," DASA (Dec. 1962), PX-448. Milk is also an important source of iodine-131 and related isotopes that will be absorbed and will bombard the tiny thyroid glands of children at a dosage rate higher than that for an adult consuming the same quantities. See e.g., National Council on Radiation Protection and Measurements, Protection of the Thyroid Gland in the Event of Release of Radioiodine, NCRP Rep. No. 55 (1977), DX-1179, at 9-10 ("since the thyroid gland increases in size with age, the juvenile gland will receive a larger average absorbed dose per millicurie intake than will the adult. . . "); Pendleton, et al., "Iodine-131 in Utah during July and August 1962," 141 Science 640, 641 (1963), PX-672.

These examples illustrate that the risks of internal exposure to fallout radioactivity are a product both of the specific properties of each radionuclide and the characteristics of the organisms—including humans—that ingest them. Dr. John Gofman has detailed some of the most important variables:

> For each radionuclide there are several crucial factors that will determine how much energy is actually deposited in the tissue, including:

a. the route of entry of the radionuclide into the body.

b. the fraction of the administered dose that actually reaches the tissue of interest.

c. the biological rate of removal of the radionuclide from that tissue.

d. the amount of radiation the tissue of interest receives from the portion of the radionuclide deposited in tissues other than the one of interest (so-called crossfire radiation). . .

e. the number of microcuries of the radionuclide taken in (crucially dependent on the correct measurement of the strength of the radionuclide source).

f. careful calculation of the average energy of the beta [or alpha] particles emitted, of any ancillary gamma rays emitted and of any loss of radiation out of the specified tissue.

g. metabolic or other factors that might alter the distribution of the radionuclide in the various tissues of the people studied.

J. Gofman, Radiation and Human Health 44 (1981), PX-1046. See also Hamilton, "The Metabolism of the Fission Products and the Heaviest Elements," 49 Radiobiology 325-43 (1947), PX-640; Dunning, "Criteria for Establishing Short-Term Permissible Ingestion of Fallout Material," 19(?) Am. Ind. Hyg. Assoc. J. 111-20 (Apr. 1958), DX-701; Finkel, "Relative Biological Effectiveness of Internal Emitters," 67 Radiology 665 (Nov. 1956), PX-669; AGC Symposium, "The Shorter-Term Biological Hazards of a Fallout Field," 147-232 (Dec. 1956) PX-699/DX-641; K. Z. Morgan, "Tolerance Concentrations of Radioactive Substances," 51(4) J. Phys. & Colloid Chem. 984-1003 (July 1947), PX-823.

One of the other factors affecting the distribution of radionuclides in various tissues is one wholly independent of either nuclide or organism: in food chains that contain an abundance of stable nutrient elements (e.g., calcium, iodine-127, potassium), absorption of the chemically analogous radionuclides (e.g., strontium-90, the iodine isotopes, cesium-137) is significantly reduced in comparison to ecological systems that are nutrient-poor. See 1 F. W. Whicker & V. Schultz, Radioecology: Nuclear Energy and

the Environment142 (1982). A person whose diet provides an abundant supply of potassium, for example, will absorb and retain less cesium-137 from contaminated food than will someone whose diet lacks that nutrient. Similar effects are observed in livestock, poultry and fish. Fresh water fish, for example, will retain cesium-137 and strontium-90 in their tissues at a rate 200 times greater than will salt water fish. See id. at 143, tbl. 1.

Radioactive isotopes of nutrient elements, or of elements that are chemically similar to nutrients, are far more likely to be absorbed and retained than many of the relatively insoluble metal oxides found in fallout debris. A frequently used method of comparing relative rates of retention is computation of the biological half-life. The biological half-life is simply the time period in which one half of a given quantity of absorbed material leaves the body. The rate at which a particular radionuclide leaves tissue varies from organ to organ:

> The biological excretion rate of an element from the human body is not necessarily the same for the whole body and for a particular organ. In fact, in most cases, the biological elimination rates are different for different organs and for the body as a whole. For example, the biological half-life of iodine is 138 days for rejection from the thyroid, 7 days for the kidneys, 14 days for the bones, and 138 days for the whole body.

N. Tsoulfanidis, Measurement and Detection of Radiation 497 (1983).

Before the internal exposure attributed to a particular contaminant may be evaluated, the biological half-life of the nuclide must be adjusted to account for radioactive decay. While iodine-131 has a biological half-life (in the thyroid) of 138 days, its 8-day radioactive half-life determines that an absorbed quantity of iodine-131 will have decayed almost entirely before a meaningful fraction of it is eliminated by the body. The energy released by radioactive decay will largely be diffused along thousands of ionization tracks in the absorbing tissue. Adjustment of the two half-lives, radioactive and biological, yields an effective half-life of 7.6 days.

The radioactive, biological and effective half-lives for several common radionuclides are listed in Table 8.

TABLE 8
Radiological, Biological, and Effective Half-Lives of Certain Common Isotopes

Isotope	Organ of reference	Radiological half-life	Biological half-life	Effective half-life
^{3}H	Total body	12.3 y	12 d	12 d
^{14}C	Total body	5,700 y	10 d	10 d
	Fat		12 d	
	Bone		40 d	
^{23}P	Total body	14.3 d	257 d	13.5 d
	Liver		18 d	8 d
	Bone		1,115 d	14.1 d
	Brain		257 d	13.5 d
^{40}K	Total body	1.28×10^{9} y	58 d	58 d
^{55}Fe	Total body	1,100 d	800 d	463 d
	Spleen		600 d	388 d
	Lungs		3,200 d	819 d
	Liver		554 d	368 d
	Bone		1,680 d	665 d
^{57}Fe		45.1 d		
^{99m}Tc	Total body	0.25 d	1 d	0.2 d
	Kidneys		20 d	0.25 d
	Lungs		5 d	0.24 d
	Skin		10 d	0.24 d
	Liver		30 d	0.25 d
	Bone		25 d	0.25 d
^{129}I	Total body	1.725×10^{7} y	138 d	138 d
	Thyroid		138 d	138 d
	Kidneys		7 d	7 d
	Liver		7 d	7 d
	Spleen		7 d	7 d
	Testes		7 d	7 d
	Bone		14 d	14 d
^{131}I	Thyroid	8 d	138 d	7.6 d
^{236}U	Total body	7.12×10^{8} y	100 d	100 d
	Kidneys		15 d	15 d
	Bone		300 d	300 d
^{236}U		4.66×10^{9} y		
^{239}Pu	Total body	24,000	175 y	175 y
	Liver		82 y	82 y
	Kidneys		87.7 y	87.7 y

N. Tsoulfanidis, Measurement and Detection of Radiation 498 (1983).

If the radioactive and biological half-lives are known, the effective half-life may be calculated according to the formula:

$$Te = \frac{(Tr)(Tb)}{Tb + Tr}$$

where Te is the effective half-life, Tr the radioactive half-life and Tb the biological half-life. J. Gofman, Radiation and Human Health 422-24 (1981), PX-1046.[76] Computation of the total radiation exposure or dose rate from the effective half-life of a specific radionuclide requires more than simple mathematics:

> As a result of the combined radioactive and biological elimination of a radioisotope from the whole body or from an organ, the dose rate to the body or the organ is not constant over time. Consider an amount of a certain radioisotope that delivers a dose rate equal to DE(O) at the time of ingestion. If the effective half-life of the isotope is Te, the total dose delivered to the body, or the organ, over a period of time T is
>
> $$DE_T = \int_0^T DE(0)e^{-\lambda_e t}\,dt = \frac{DE(0)}{\lambda_e}(1 - e^{-\lambda_e T})$$
> $$= \frac{DE(0)}{\ln 2} T_e \left[1 - \exp\left(-\ln 2 \frac{T}{T_e}\right)\right]$$
>
> If the time period T [is much greater than] Te, then
>
> $$DE_{inf} + \frac{DE(0)}{\ln 2} Te$$

N. Tsoulfanidis, Measurement and Detection of Radiation 497-499 (1983). Crucial to the whole calculation is the use of accurate information concerning the quantity of radionuclide ingested; the formula is useless if DE(O) is unknown. How much fallout debris one ingests and absorbs is a product of all of the variables previously discussed. Plainly, accurate estimation of internal radiation exposure is not a simple process. Exposure to fallout debris involves all of these variables, and the sum of these calculations for not one, but dozens of biologically significant radionuclides. See e.g., Y. Ng et al., "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices—IV. Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere," LLRL (May 1968), PX-720.

The complexity of the problem yields a great temptation for everyone to generalize. Abstract computations derived from hypothetical models are far easier than painstaking calculations based upon exacting observation and analysis. It is far easier to project a hypothetical dose of radiation received worldwide from an evenly distributed and known quantity of one radionuclide than it is to calculate in 1984 the total dose, that Sally Jones or Timmy Smith received by 1962 from eating unknown quantities of food or milk from unknown sources contaminated with unknown yet real quantities of fallout radioactivity of largely unknown composition. Consequently, hypothetical (especially worldwide) projections are common in the literature; analyses of specific persons or particular small communities are rare.

The record in this case is replete with examples of analysis based upon worldwide or nationwide projections. More localized studies are far fewer in number. Of the group concerning the Nevada/Utah/Arizona area, several were undertaken only after the commencement of this lawsuit. A common characteristic of each study, however, is the presence of at least one hypothetically derived generalization about phenomena which are incurably variable—and unpredictable at least to some extent.

How much fallout radioactivity follows the complex network of environmental and biological pathways to reach man is determined in the first instance not by the dynamics of the pathways but by the initial amount of the fallout debris that is deposited at a particular place in time. This initial distribution pattern is itself a product of important and often unpredictable variables. In the standard handbook on the subject—published in 1950, a year before Nevada testing began—the authors observed:

> With regard to the internal radiation hazard, it is not possible to make any sound estimate of the amount of material which is likely to be ingested in various circumstances. A person working under normal indoor conditions, for example, would absorb much less than one engaged in an occupation in which there was much dust. Children, because of their habits and closeness to the ground, would be expected to ingest more than adults. These factors would greatly complicate a rehabilitation program, and make it almost impos-

sible to attempt to assess universal permissible contamination levels.

J. Hirschfelder, S. Glasstone, et al., The Effects of Atomic Weapons ¶ 12.74 at 396 (1950), PX-690/DX-470.

C. Factors Affecting Fallout Distribution

The fallout yield of a nuclear explosion is predictable with some degree of accuracy, so long as certain information about the device is known. How airborne fallout is ultimately dispersed in the environment, however, is far less amenable to abstract calculation. Fallout distribution is influenced by a series of variables which seemingly multiply without end. Yet fallout dispersal has been the subject of repeated generalization at the theoretical level. Monitoring techniques have assumed and relied upon the soundness of various dispersal models. The validity of many radiation exposure and dosage estimates in turn has depended in large part on the accuracy of those monitoring techniques.

From the moment of detonation, radioactive material is dispersed unevenly; while the head of the mushroom cloud contains 90% of the fallout activity, distribution within the cloud is anything but uniform. As the cloud expands, large fallout particles begin falling to the surface, while winds propel smaller particles of radioactive dust away from the site of the explosion. Hot gases diffuse quickly into the surrounding air, blending with the environment in the eddies of numberless air currents.

Weather has a dominant influence on how and where a fallout cloud is dispersed. Important variables include the altitude to which the cloud rises and the wind speed and direction at the higher altitudes through which the cloud may rise. The degree of wind shear, i.e., a change in wind direction at different altitudes, can materially affect the dispersal of the cloud, yielding a wider, shorter spread of particles than would be observed if no wind shear was present. Precipitation may dramatically alter the rate at which fallout particles fall to the surface; if the fallout cloud enters a storm cloud system, a "rainout" could bring 90+% of the

fallout debris to the surface in one hour. See S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶¶ 9.57-9.74 (3d ed. 1977) DX-1242.

During much of the era of atmospheric nuclear testing, considerable attention was paid to the analysis of fallout distribution patterns, using data gathered by teams of fallout monitors on the ground, by aircraft which pursued fallout clouds in flight and by automatic sampling and recording instruments placed at selected locations across the country. The empirical data gathered through monitoring describes (at least to some extent) the fallout process. Scientists quickly developed several varieties of mathematical models of fallout in an effort to explain and to predict the patterns in which nuclear residues would be deposited.[77]

As carefully constructed as the models have been, however, they admittedly offer only general guidance as to what the actual fallout distribution from a given detonation will be. That guidance is to be handled with caution:

> Idealized fallout contour patterns have been developed which represent the average fallout field for a given yield and wind condition. No attempt is made to indicate irregularities which will undoubtedly occur in a real fallout pattern because the conditions determining such irregularities are highly variable and uncertain. . .

S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 9.83 at 423 (3d ed. 1977), DX-1242 (emphasis added). The uncertainty factor can be considerable. Consider, for example, the Rand Corporation's "Project Sunshine" report in 1953: by collecting samples of dust on sticky gummed paper at 92 monitoring stations in the United States and 15 more outside the country, the project sought to estimate the distribution of fallout radioactivity—particularly strontium-90—produced by the "TUMBLER/SNAPPER" test series in Nevada (April to June 1952). The Report notes that

> It would appear that unless the efficiency of collection of the gummed paper was as low as 10 to 15 percent, 80 percent or more of the Tumbler/Snapper activity remained suspended

> in the atmosphere for periods after June 18, 1952, or that large quantities of activity fell in areas not sampled.

Report on "Project Sunshine," at 30 (Aug. 6, 1953), PX-1027/DX-743 (emphasis added). In other words, nearly two weeks after the last TUMBLER/SNAPPER explosion (June 5, 1952) the monitoring system could not account for 80+% of the beta-emitting fallout debris from that series. Perhaps as the report suggests, it was still airborne. Perhaps not. One thing is certain: the TUMBLER/SNAPPER fallout went somewhere.

Fallout studies conducted during the BUSTER/JANGLE series conducted earlier that year (1952) described considerable difference in fallout distribution:

> Variations in the measured concentrations [on] the ground were large and frequent, and in many cases could not be adequately explained. Consequently, the exact meaning of the results of the surface monitoring program is not known. Research should be undertaken to determine what specific meteorological and other factors cause these variations.

"Transport of Radioactive Debris from Operations Buster and Jangle," WT-308 (EX), PX-739/DX-133, at 112.

Even the fraction of the fallout collected at the sampling stations used for TUMBLER/SNAPPER, or the forty-four U. S. and forty-nine worldwide stations used to monitor fallout from Operation Ivy, a Pacific test program, showed tremendous variation:

> However, as we have seen from the Tumbler/Snapper and Ivy fallout measurements, the fallout from individual explosions varies by a factor of 200, either way, from the average for stations outside the test sites. Consequently we can expect that even if all the Sr^{90} from the A-bomb explosions has fallen out, the concentration of Sr^{90} will vary over the earth's surface within this factor. Because of this possible extreme variation of Sr^{90} deposition—localized but long-range—Sr^{90}

contamination may well be the most important aspect of the Sunshine project.

Id. at 34, PX-1027/DX-743 (emphasis in original). The report further observes that the observed range of strontium-90 concentrations in the environment was burdened "with a large measure of uncertainty." Id. Some error in gummed paper monitoring may have resulted from the assay procedures used by the AEC. At the agency's New York laboratory, the beta "activity of each sample is counted for 20 minutes or 640 counts whichever comes first." Atomic Energy Comm'n, Assuring Public Safety in Continental Weapons Tests 106-107 (1953) PX-740; no sample, it seems was permitted to be "hotter" than 640 counts. Additionally, before counting, the samples of gummed paper or filter paper were "dry ashed in an electric furnace," id., at temperatures high enough to drive away isotopes of iodine, an important fission product, and possibly other "volatile" products as well.

Finally, it is interesting to note that beta-emitting fallout levels in Utah—immediately downwind from the NTS—were monitored by one sampling station in Salt Lake City, while Colorado had six such stations, Montana seven, New York nine, and California ten. See Fig. 8.



The arcs are 500 miles apart.

The model of fallout distribution that justifies placement of eight monitoring stations in western New York while leaving much of Utah, Nevada and northern Arizona vacant is not described. Perhaps the NTS monitoring network was deemed adequate for communities surrounding the NTS. The 1953 Sunshine Project Report does indicate, however, that the highest peak and average beta measurements following TUMBLER/SNAPPER were recorded in Nevada, Utah and Idaho (two monitoring stations). Project Sunshine, PX-1027/DX-743, at 28.

As a rule, NTS monitors counted only gamma radiation at off site locations in Nevada and Utah, ignoring the beta count altogether. See Part VIII, infra.

Those who undertook the actual monitoring of real nuclear fallout in the early 1950s soon rediscovered something not predicted—or predictable—in the idealized mathematical models: the existence of "hot spots," or small areas of noticeably higher fallout deposition in the same general geographic areas. A "hot spot" might display two or three—or even 2 or 3 thousand—times the radioactivity found in neighboring terrain.[78]

Hot-spots have appeared in curious places. Perhaps the most noticed example was the hot-spot discovered near Troy, New York, following a rainstorm in 1953. Following the storm, Geiger counter readings ranged from 5 milliRoentgens per hour downtown to localized hot-spots reading as high as 120 milliRoentgens per hour. See e.g. Clark, "The Occurrence of an Unusually High-level Radioactive Rainout in the Area of Troy, N.Y.," 119 Science 619 (1954). The Troy hot-spot developed 36 hours after a detonation in Nevada more than 2,000 miles away.

On a number of occasions, monitors working on and off the Nevada Test Site detected many localized points of higher fallout deposition which differed by a factor of 2 or 3—or much more—in fallout activity compared to readings taken a few feet away.

Other factors complicate the fallout distribution picture even further. Once on the ground, fallout particles may be resuspended and redistributed by wind and weather, or by human activities.

such as farming or ranching. Rain may wash settled particles into streams and ponds. The contour and vegetation of the landscape plays a significant role in shaping the ultimate patterns of fallout deposition. Even the size of the fallout particles themselves can have a significant effect on when and where fallout is deposited:

> Because particles of different sizes descend at different rates and carry different amounts of radioactive contamination, the fallout pattern will depend markedly on the size distribution of the particles in the cloud after condensation has occurred. In general, larger particles fall more rapidly and carry more activity, so that a high proportion of such particles will lead to greater contamination near ground zero, and less at greater distances, than would be the case if small particles predominated.

S. Glasstone & P. Dolan, The Effects of Nuclear Weapons, supra, ¶ 9.62 at 415. Very tiny particles may remain suspended in air for a long period, irradiating persons and objects as they pass by, but without leaving substantial fallout deposited on the ground. Each time that a nuclear device is detonated in the atmosphere, or its residues are permitted to enter the atmosphere (e.g., venting from an underground test), every one of these variables interact in varying degrees to determine where the fission products, unspent uranium or plutonium and induced activity products will finally come to rest.

D. Factors Affecting Total Exposure to Fallout Radiation

The most significant single factor determining the extent of radiation exposure from nuclear fallout is time. As noted above, the fission and induced activity products of a nuclear explosion are often very unstable and decay very rapidly. Theoretical estimates by Glasstone and others predicted an overall decay rate expressed as $t^{-1.2}$, where t represents the time elapsed since detonation. S. Glasstone & P. Dolan, The Effects of Nuclear Weapons, supra, ¶¶ 9.146-9.153 at 450-52. Actual measurements following some of the Nevada tests indicated that the decay rate in the short period immediately following the explosion was even higher (e.g., $t^{-1.3}$ or $t^{-1.4}$). A large portion of the radiation emitted by fallout materials

will thus be spent in the first hours and days following the detonation. While some fallout components such as plutonium, cesium-137, strontium-90, and iodine-129 will persist in the environment for many years following a test, most of the 200 or more radionuclides decay and disappear far more quickly.

While the high rate of decay of fallout materials materially reduces the risk of exposure over a long period, it also indicates that contact with fallout in the first minutes or hours following detonation can easily result in serious radiation exposures.

Besides the mere passage of time, other factors operate to reduce, or attenuate the degree of radiation exposure experienced from fallout. From an external exposure standpoint, distance from radioactive materials reduces the effective dose, particularly from alpha and beta radiation. The highly ionizing quality of alpha radiation allows it only a short range in air before the particle energies are spent, perhaps a distance of a few centimeters, or an inch or two. Beta particles, as low-LET radiation, can travel greater distances by virtue of their weaker ionizing qualities: "[m]any of the beta particles emitted by the fission products traverse a total distance of 10 feet (or more) in the air before they are absorbed. However, because the particles are continually deflected by electrons and nuclei of the medium, they follow a tortuous path, and so their effective (or net) range is somewhat less." S. Glasstone & P. Dolan, The Effects of Nuclear Weapons, supra, ¶ 9.115 at 440. More dense materials, e.g., water, wood, glass, paper, and brick, experience far greater ionization along the particle tracks, which consequently are much shorter, perhaps one-thousandth of the range observed in air. See id., ¶ 9.116.

Where, however, the material exposed is living tissue, either through deposit of particles on the skin or inhalation or ingestion of fallout materials into the body, alpha and beta radiations can pose a serious risk of acute and long-term injury. Clearly, radiation exposure from fallout can be materially reduced simply through physical processes, i.e., removal of fallout particles from skin, clothing, hair and immediate surroundings by thorough washing, use of face masks around contaminated dust to avoid inhalation,

and careful handling of food and water to avoid or minimize contamination by radioactive materials.

Gamma radiation ionizes far fewer air molecules as it passes through, permitting it a far greater range in air than the charged-particle radiations. As described previously, gamma radiation is a form of electromagnetic radiation similar in its physical qualities to visible light, radio waves, and ultraviolet rays. The far greater energy of gamma radiation permits it to penetrate and pass through dense materials with a range considerably greater than either alpha or beta particles. Clothing stops alpha particles and most beta particles, but is poor shielding against gamma rays, many of which will pass through both fabric and wearer relatively unimpeded. More substantial materials, such as building materials or soil, can significantly reduce or attenuate gamma radiation exposures when placed between the source and the person at risk. Table 9 lists the relative fraction of gamma exposure experienced by a person within a protective structure contrasted with one standing unprotected in a fallout field.

TABLE 9

Fallout Gamma-Ray Dose Transmission Factor
for Various Structures

Structure	Dose transmission factor
Three feet underground	0.0002
Frame house	0.3–0.6
Basement	0.05–0.1
Multistory building (apartment type):	
Upper stories	0.01
Lower stories	0.1
Concrete blockhouse shelter:	
9-in. walls	0.007–0.09
12-in. walls	0.001–0.03
24-in. walls	0.0001–0.002
Shelter, partly above grade:	
With 2 ft. earth cover	0.005–0.02
With 3 ft. earth cover	0.001–0.005

S. Glasstone & P. Dolan, The Effects of Nuclear Weapons, supra, table 9.120 at 441. In terms of alpha, beta and gamma radiation, the potential exposure that may be experienced during a radioactive fallout event can be materially reduced simply by staying indoors (assuming the contamination is kept outdoors) until the exposure hazard has abated. Washing of fallout materials into the soil, either by rainfall or deliberate effort, will further attenuate the rate of gamma exposure, as does turning under the soil itself when the surface is contaminated with fallout. The shielding effect of buildings and dwellings is augmented simply by washing down the roof and large wall surfaces, reducing the effect of being geometrically surrounded by radiation sources. See id., ¶¶ 9.14-9.20 at 439-441.

Fallout material which has been washed into soil, or has been deposited at a distance, or behind surface features or structures—embankments, walls, or other solid obstructions—presents far less exposure hazard than radioactive residue in close proximity or direct contact with the persons involved.

Weathering, shielding, time, and distance all have some impact which lessens the dose of radiation actually absorbed by people in a potentially hazardous fallout situation, or other instance of radioactive contamination. These factors may in some cases reduce actual exposure to one-half or less of the potential dose rates that may arise in a given situation. However, whether one gains the full benefit of the gamma-shielding effects of housing materials, for example, depends heavily upon human factors. It depends in part upon knowing or being effectively warned to seek shelter indoors when fallout materials may be precipitating outdoors.

Internal exposure arising from ingestion, absorption or inhalation of radioactive fallout materials presents some different problems governed by additional variables. The complex pathways by which radioactive materials make their way into biological and environmental systems have already been mentioned in this Part. See also, F. W. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment (1982) (2 vols.). Where nuclear contamination is present, great care must be taken to avoid inhaling or consuming fallout materials in food and water. Once ingested or

inhaled, the degree of exposure actually experienced depends upon the highly variable physical and chemical qualities of each individual radionuclide. Many fallout contaminants inhaled or ingested as dust are in the form of relatively insoluble metal oxides. These may pass quickly through the body, radiating tissues as they pass by, but not persisting in any of them for extended lengths of time. Others, whose solubility is greater and which may have chemical properties similar or identical to important nutrients, can quickly find their way into sensitive human tissue. As noted above, the radioactive isotopes of iodine quickly migrate to thyroid gland tissues; strontium and barium isotopes find their way to important bone tissue. Once absorbed, the fallout radionuclides diminish in accordance with a combination of radioactive and biological half-lives. See Part III (B), supra. Some contaminants, such as plutonium with its effective half-life in the bones of 400 years, become practically permanent sources of ionizing radiation within the body itself. See e.g., Tr. at 2791 (testimony of Dr. Karl Z. Morgan).

The different ecological characteristics of several important radionuclides are listed in Table 10. 1 F. W. Whicker & V. Schultz, Radioecology: Nuclear Energy & the Environment 163-166 (1982) (table). The list is not exhaustive; the complex processes of the nuclear fission furnace produce 200 other nuclides, each having distinct chemical, physical or radioactivity properties. See Appendix A, infra. Combined with unspent fuel and neutron-activated radionuclides,

> The fission products can produce injury either as an external source of radiation or, if they gain entry into the body, by acting as an internal radioactive poison, quite analogous to radium poisoning. This latter consideration is a major concern, since the amounts required within the body to produce injurious effects are minute compared to the quantities necessary to induce damage by external beta and gamma irradiation.

Hamilton, "The Metabolism of the Fission Products and the Heaviest Elements," 49 Radiobiology 325 (1947), PX-640. Prediction of internal exposure from such varied toxins becomes an

TABLE 10

General Ecological Properties of Selected Radionuclides

Radionuclide ($T_{1/2}$)	Sources	Nutrient analogs	Principal biospheric reservoirs	Important exposure modes	Degree of food chain transport	Successive trophic level concentration	Critical organs (vertebrates)	Assimilation	Retention(T??)
				Nonmetals					
^{3}H (12 year)	Cosmic Fission Activation	H	Hydrosphere (HTO)	Ingestion, uptake, absorption, inhalation	High	Approaches unity	Total body	Complete	Low (days)
^{14}C (5600 year)	Cosmic Activation	C	Atmosphere (CO_2), lithosphere ($C_x CO_3$)	Ingestion, absorption, uptake	High	Approaches unity	Fat, total body	Complete	Low (days)
^{32}P (14 day)	Activation	P	Biota, soil	Ingestion, uptake	High	< 1.0	Bone	High	Low-high (days-years)
^{131}I (8 day)	Fission	I	Biota, soil	Ingestion, absorption, inhalation	High	10^{3} (thyroid/ plants)	Thyroid	High	Moderate (weeks-months)
				Light metals (Group IA)					
^{40}K (1.3 x 10^{9} year)	Primordial	K	Lithosphere	Ingestions, absorption, uptake, external γ	High	Approaches unity	Total body	High	Moderate (weeks)
^{84}Rb (19 day)	Fission, activation	K	Biota, soil	Ingestion, absorption, uptake	High	Approaches unity	Total body	High	Moderate (weeks)
^{137}Cs (30 year)	Fission	K	Soil, sediments	Ingestion, absorption, external γ	High	Approaches 3.0	Total body	High	Moderate (weeks-months)

No. C 79-0515-J

TABLE 10 (continued)

General Ecological Properties of Selected Radionuclides

Radionuclide ($T_{1/2}$)	Sources	Nutrient analogs	Principal biospheric reservoirs	Important exposure modes	Degree of food chain transport	Successive trophic level concentration	Critical organs (vertebrates)	Assimmilation	Retention(T??)
				Light metals (Group IIA)					
^{45}Ca (160 day)	Activation	Ca	Biota, soil	Ingestion, absorption, uptake	High	< 1.0	Bone	High	Moderate-high (weeks-years)
^{90}Sr (28 year)	Fission	Ca	Soil, biota	Ingestion, absorption, uptake	High	< 1.0	Bone	Moderate	High (years)
^{140}Ba (13 day)	Fission	Ca	Biota, soil	Ingestion, absorption, uptake	High	< 1.0	GI, bone	Moderate	Moderate (weeks)
^{224}Ra (1600 year)	^{232}U decay series	Ca	Lithosphere	Ingestion, absorption, uptake, external γ	Moderate	< 1.0	Bone	Moderate	High (years)
				Noble gases					
^{37}A (35 day)	Activation	None	Atmosphere	Submersion	Negligible	Negligible	Skin	Negligible	Negligible
^{85}Kr (11 years)	Fission	None	Atmosphere	Submersion	Negligible	Negligible	Skin	Negligible	Negligible
^{133}Xe (5.3 day)	Fission	None	Atmosphere	Submersion	Negligible	Negligible	Whole body	Negligible	Negligible
^{222}Rn (3.8 day)	^{238}U decay series	None	Lithosphere, atmosphere	Inhalation of daughters	Negligible	Negligible	Lung (from daughters	Negligible	Negligible
				Heavy metals					
^{51}Cr (28 day)	Activation	None	Soil, sediment	Adsorption, inhalation	Very low	< 10^{-2}	Lung, GI	Very low	Moderate-high (years)
^{54}Mn (300 day)	Activation	Mn	Soil, sediment	Ingestion, inhalation,	Moderate-high	< 1.0	GI, liver, lung	Moderate	Moderate (days-weeks)

TABLE 10 (continued)

General Ecological Properties of Selected Radionuclides

Radionuclide ($T_{1/2}$)	Sources	Nutrient analogs	Principal biospheric reservoirs	Important exposure modes	Degree of food chain transport	Successive trophic level concentration	Critical organs (vertebrates)	Assimmilation	Retention(T??)
^{55}Fe (2.6 years)	Activation	Fe	Soil, sediment	adsorption, external γ Ingestion, inhalation, adsorption	Moderate-high	<1.0	Spleen, lung	Moderate	Moderate-high (years)
^{60}Co (5.2 years)	Activation	Co	Soil, sediment	Ingestion, adsorption, inhalation, external γ	Moderate-high	<1.0 - 10?	GI, total body, lung	Moderate	Low (days)
^{65}Zn (245 day)	Activation	Zn	Soil, sediment	Ingestion inhalation adsorption external γ	Moderate-high	<1.0	Total body, liver,lung	Moderate	Moderate-high (months-years)
^{95}Zr (65 day)	Fission	None	Soil, sediment	Absorption inhalation external γ	Very low	<10?	GI, lung	Very low-negligible	Moderate-high (months-years)
^{99}Tc (2 x 10^5 years)	Fission	None	Biota, soil	Ingestion Inhalation uptake	High	<1.0	GI, lung	High	Low (days)
^{106}Ru (1 years)	Fission	None	Soil, sediment	Ingestion inhalation adsorption external γ	High	<1.0	GI, lung	Low-moderate	Low (days)
^{210}Pb (20 years)	^{238}U decay series	None	Soil, sediment	Ingestion inhalation adsorption	High	<1.0 - 10	Kidney, lung	Moderate	High (years)
^{210}Po (138 day)	^{238}U decay series	None	Soil, sediment	Ingestion inhalation adsorption	High	<1.0 - 10	Spleen, kidney, lung	Moderate	Moderate (weeks)

TABLE 10 (continued)

General Ecological Properties of Selected Radionuclides

Radionuclide ($T_{1/2}$)	Sources	Nutrient analogs	Principal biospheric reservoirs	Important exposure modes	Degree of food chain transport	Successive trophic level concentration	Critical organs (vertebrates)	Assimmilation	Retention(T??)
				adsorption, external γ					
				Rare Earths					
^{91}Y (58 day)	Fission	None	Soil, sediment	Ingestion inhalation adsorption	Low	< 0.1	GI, bone, lung	Very low-negligible	High (years)
^{140}DLa (40 hr)	Fission	None	Soil, sediments, biota	Ingestion inhalation adsorption external γ	Low	< 0.1	GI	Very low-negligible	Moderate (1 – 3 years)
^{144}Ce (285 day)	Fission	None	Soil, sediment	Ingestion inhalation adsorption external γ	Low-moderate	<0.1	GI, bone, lung, liver	Very low-negligible	Moderate (1 – 5 years)
^{147}Pm (2.6 year)	Fission	None	Soil, sediment	Ingestion inhalation adsorption	Low	< 0.1	GI, bone, lung	Very low-negligible	Moderate (2 – 5 years)
				Actinides					
^{232}Th (1.4 x 10^{10} year)	Natural	None	Lithosphere	Ingestion inhalation external γ	Very low	< 10 ?	Bone, lung	Very low-negligible	High (years)
^{238}U (4.5 x 10^{9} year)	Natural	S, Se?	Lithosphere	Ingestion inhalation uptake external γ	Low-moderate	< 1.0	GI, kidney, lung	Very low	Moderate (months)
^{239}Pu (2.4 x 10^{4} year)	Activation	None	Soil, sediment	Ingestion inhalation Adsorption	Very low	< 10 ?	Bone, lung	Very low-negligible	High (years)

No. C 79-0515-J

exceedingly complex task, for it is apparent that "no radionuclide that is produced should be ignored until a critical analysis demonstrates that it is insignificant." Y. Ng, et al., Prediction of the Maximum Dosage to Man From the Fallout Nuclear Devices:—IV. Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere, Lawrence Radiation Laboratory, UCRL-50163 Part IV (1968), PX-720, at v. [hereinafter cited as "LLRL Handbook for Estimating Maximum Internal Dose"]. While many fission products decay and nearly vanish before making their way into the food chain, others persist with tremendously variable effect upon the degree of internal radiation exposure received.

Even where metabolic or ecological variables can be ignored, as in estimation of external alpha, beta, and gamma dose from exposure to fallout debris, the calculations are not simple. See e.g., Broido & Teresi, "Analysis of the Hazards Associated With Radioactive Fallout Material (I)—Estimation of α- and β- Doses," 5 Health Physics 63-69 (1961), PX-563.

Clearly, where exposure to radioactive fallout is concerned, the complexity and the variability of the multitude of factors makes careful and comprehensive monitoring and measurement a genuine necessity, if external and internal doses are to be accurately evaluated. Assessment of the risks posed by the infiltration of nuclear debris into the daily life of off-site residents in communities in Utah, Nevada and Arizona is a demanding task at best. Where the available data generated from actual measurements of fallout activity and contamination is grossly inadequate and incomplete, the difficulty of the task is compounded a thousandfold. See Parts VIII, IX, infra.

IV. BACKGROUND: BASIC PRINCIPLES OF HEALTH PHYSICS

A. Units Used in Radiation Dosimetry

The testimony and exhibits in the record as well as the scientific literature concerning radiation and health make use of a variety of units to express or describe the amounts of radiation people are exposed to or have absorbed into their tissues. In evaluating infor-

mation and analysis of radiation hazards, it is useful to identify the specific units being used and the concept and quantity that each unit expresses.

> Radiation-induced damage to biological tissue results from the absorption of energy in or around the tissue. The amount of energy absorbed in a given volume of tissue is related to the type, energy, and number of radiations traversing the tissue volume, and the interactions which occur between the radiations and the atoms and molecules of the tissue.

1 F. W. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment 63 (1982).

(1.) Rad

The most commonly used unit to describe radiation dose, that is, the actual amount of ionizing radiation absorbed by living tissue, is the rad. Measurement of radiation dose in rads is accomplished by dividing the total radiation energy delivered by the mass (in grams) of the tissue which absorbs it. A rad expresses an energy/mass ratio:

> Historically, the erg has been used to describe energy delivered by ionizing radiation. If 100 ergs of energy are deposited in 1 gram of tissue, the tissue is said to have received 1 rad of radiation. . . .
>
> The definition of the rad says nothing about the time it takes to deliver 100 ergs per gram of tissue. In some cases good reason exists to be concerned about the rate of delivery of radiation, and in these cases we would express radiation doses in terms of rads per minute, rads per hour, or rads per year. For many purposes we shall be concerned with total rads delivered, and not with their rate of delivery.

J. Gofman, Radiation and Human Health 46 (1981), PX-1046 (emphasis in original).

Like other units discussed so far, the rad may be more conveniently expressed in fractional form:

1 millirad (mr) = 0.001 rads (or 10^{-3} rads)

1 microrad (μr) = 0.000001 rads (or 10^{-6} rads)

Larger multiple units, such as kilorad (1,000 rads) have little application to measurement of doses to specific individuals; absorbed in a short time, such a dose would likely be fatal. See S. Glasstone & P. Dolan, The Effects of Nuclear Weapons 577 (3d ed. 1977), DX-1242. Recently, however, more use has been made of a unit from the international system of units, the Gray. A Gray (Gy) represents the absorption of 1 joule (10^7 ergs) of energy in 1 kilogram (1,000 grams) of tissue. Simple calculation disclosed that 1 Gray represents 10^4 ergs per gram of tissue, or a dose equalling 100 rads. J. Gofman, Radiation & Human Health, supra, at 46. A dose of one rad would equal 0.01 Gray. 50 millirads would equate to 0.0005 Gray.[79]

Except for a few recent scientific publications, the testimony and exhibits in this case speak in terms of rads rather than Grays, as will the text of this opinion.

Radiation dose expressed in rads can be related to radioactivity expressed in curies through simple mathematical calculation. Assuming that all of the energy released by the beta decay of 1 pico- curie (PCI) of radioactive material evenly dispersed in 1 kilogram of tissue is actually absorbed in the tissue, the dose rate to that tissue, expressed in rads per hour, would equal:

Dose rate (rads/hr) = $(2.134 \times 10^{-9}) \times$ (average decay energy [MeV])

See id. PX-1046, at 418-19. The total dose received to the kilogram of tissue (e.g., the lungs of an adult person), may be calculated using an equation previously discussed:

Total Dose (rads) = (dose rate/0.693) x (T_e) x (k)

where T_e is the effective half-life of a specific radionuclide, see e.g. Table 8, supra, and k is a mathematical term which converts T_e into hours. See N. Tsoulfanidis, Measurement and Detection of

Radiation 499 (1983).[80] For example, 1 pCi of iodine-131, with an average decay energy approximating 0.6 MeV, would deliver ionizing radiation in the form of beta particles at the rate of 1.28×10^{-9} rads per hour, for a total dose of nearly 3.37×10^{-7} rads, or 0.33 microrads, based upon an effective half-life of 7.6 days. This is a very small dose of beta radiation. The picocuries can add up, however, as illustrated by an example:

> By drinking milk contaminated with radioactive fallout debris, a child absorbs 20,000 PCi of iodine-131 into the tissue of her thyroid gland. The thyroid gland of a child is far smaller than a kilogram, weighing in the neighborhood of 2−4 grams. Rather than being distributed throughout a full 1,000 grams of living tissue, the energy is concentrated in far fewer radiosensitive cells. Correcting our calculation for the differences in contamination and tissue mass, we find:
>
> $$\frac{(2.134 \times 10^{-9})(0.6)(20{,}000)1000/4)}{0.693} \times (7.6 \text{ days})(24 \text{ hr/day})$$
> $$= \frac{\text{1.68 rads to the child's thyroid gland from } 131_{\text{I}}.}{\text{From a quart or so of contaminated milk, our example child could receive a radiation dose to a sensitive organ significantly higher than "background" levels due to the presence of a single fission product.}}$$

Besides iodine-131, nuclear fission produces various quantities of 11 other radioactive iodine isotopes, with half-lives ranging from a few seconds (e.g., 5.9 sec. ^{138}I) to 16 million years (^{129}I). National Council on Radiation Protection and Measurements, Protection of the Thyroid Gland in the Event of Releases of Radioiodine, NCRP Rep. No. 55 (1977), DX-1179, at 13−14, 15 (table); see Appendix A.

The example calculation is far from totally abstract. One study of milk sampled from Utah dairies shortly after the 100-kiloton SEDAN test at the Nevada Test Site in 1962 estimated the concentration of ^{131}I to vary between 0 and 800,000 pCi per litre (1.05 quarts). Pendleton, et al., "Differential Accumulation of ^{131}I From Local Fallout in People and Milk," 9 Health Physics 1253, 1255 (1963), PX-32. Further, it was estimated as a result of an

accident involving the Windscale nuclear reactor in the United Kingdom in October 1957, 20,000 curies of ^{131}I was released into the atmosphere:

> Sufficient pasture contamination occurred to require the confiscation of milk for several days in a 200-square-mile area downwind of the reactor. . . . The milk produced in a much smaller area remained contaminated above the confiscation level chosen by the British for more than a month. As a result of this confiscation and other precautionary procedures, the mean absorbed dose to the thyroid glands of children downwind of the Windscale reactor was estimated to be 16 rad, and the mean adult absorbed dose was estimated to be 4.0 rad.

NCRP Report No. 55 (1977), supra, DX-1179, at 14 (citations omitted). While radioactive fallout debris from Nevada was dispersed over a much wider area than was contamination at Windscale, a "nominal" 20-kiloton fission device yields 250,000 curies of ^{131}I, representing between 2.9 and 3.1 percent of the total fission products. Id. DX-1179, at 14 (table); 1 F. W. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment 92, 107 (tables) (1982).

The calculation performed above demonstrates that rads of radiation dose to internal organs may arise from picocuries of contamination. 250,000 curies (Ci) of ^{131}I is equivalent to 2.5×10^{17}, or 250,000,000,000,000,000 picocuries (pCi) of ^{131}I—still barely 3% of the total fission produce yield.[81] At the very least, one can say that where fallout is concerned, a lot can go a very long way.

Estimation of radiation dose from external sources, particularly multiple sources of gamma radiation, requires far more complex calculations. See e.g., H. Cember, Introduction to Health Physics ch. 6 (1969); AEC Symposium, "The Shorter-Term Biological Hazards of a Fallout Field," at 23-84 (1956), PX-699/DX-641; Broido & Teresi, "Analysis of the Hazards Associated with Radioactive Fallout Material (I)—Estimation of γ- and β- Doses," 5 Health Physics 63-69 (1961), PX-563.

Radiations of external origin that may be absorbed in liv-

ing tissues include natural or man-generated rays from the atmosphere, earth, water, and other tissues or organisms. The type of external exposure that is probably the simplest to evaluate is that resulting from a "point source" of photons. Photon emitters have a gamma ray exposure constant, termed Iγ, which has the units of roentgen per hour per curie at an air distance of 1 m. The value of Iγ, may be calculated for any gamma-emitting radionuclide and it is dependent upon the number of photons emitted per disintegration and the energies of the photons. Values of Iγ are, for example, 0.33 and 1.32 R/hr/Ci for ^{137}Cs and ^{60}Co, respectively. . . . The exposure rate (E) in roentgen per hour at any distance (d) in meters can be calculated for a point source containing A* curies by

$$E = \frac{I_\gamma A^*}{d^2}$$

Nonpoint sources and causes in which several gamma emitters are more difficult to evaluate. The case in which the radionuclide is distributed within a mass of substance is even more difficult to evaluate because of absorption and scattering of photons prior to their exit from the substance. If such complexities are great enough, direct measurement of exposure rate may be necessary.

1 F. W. Whicker & V. Schultz, Radioecology. . . , supra, 66-7 (emphasis added and footnotes omitted). See also Radiological Health Handbook, PHS Publ. 2016 (1970); K. Morgan & J. Turner, eds., Principles of Radiation Protection(1967). The tremendous variability of potential gamma and beta radiation exposures from nuclear fallout renders accurate and thorough measurement of radiation intensity an unavoidable necessity. See H. Knapp, "Gamma Ray Exposure Dose to Non-Urban Population from the Surface Deposition of Nuclear Test Fallout," T10-16457 (July 1962), PX-717.

(2.) Roentgen

The complexity of dose calculation involving gamma exposure often makes actual measurement of radiation in rad units impractical.

> Frequently, it is not convenient to measure dose in rads. In the particular case of irradiation of organisms or tissues from an external X- or gamma ray source, it is more convenient to measure the radiation exposure at the surface of the tissue of interest using an appropriate instrument or device. The dose to the tissues can be estimated from the measured exposure from theoretical considerations. The fundamental unit of radiation exposure which is applicable only to X- or gamma radiation, is the roentgen (R), which is defined as
>
> $$1\,R = 2.58 \times 10^{-4}\ \text{coul/kg air}$$
>
> This definition of the roentgen is equivalent to the production by X- or gamma rays of 1 electrostatic unit of charge of either sign per cubic centimeter of dry air at 0° C and 760 mm mercury. The roentgen quantity is defined on the basis of production of ionization in air because it is normally measured with an air-filled ionization chamber.

1 F. W. Whicker & V. Schultz, Radioecology. . . , supra, at 63 (emphasis added and footnote omitted). Simply expressed, the roentgen unit describes a certain degree of ionization caused in air by gamma rays. In the process of ionization, of course, some gamma energy is absorbed by the air, approximately 88 ergs per gram, or 0.88 rad. N. Tsoulfanidis, Measurement and Detection of Radiation 485 (1983). The greater density of living tissue results in greater absorption of the same amount of gamma radiation; a roentgen of gamma radiation in air equates with approximately 94 ergs absorbed per gram of tissue, i.e., 0.94 rads at the surface. Gamma rays with energies ranging from 0.3 MeV to 3.0 MeV permit a rough equivalence between 1 roentgen (R) of exposure and 1 rad (r) of absorbed dose in soft tissues. See S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 8.18 at 329-30 & n. 4, 638 (3d ed. 1977), DX-1242.

(3.) rem

In strict terms, a rem of ionizing radiation, or roentgen equivalent man, describes "[t]hat amount of ionizing radiation of any type which produces the same damage to man as 1 roentgen of

about 200-=kv X radiation. . . " Handbook of Chemistry & Physics, at F-103 (64th ed. Weast 1983). The rem describes a quality of ionizing radiation not encompassed by either of the first two units: neither rad nor roentgen say anything about the penetrating qualities of particular radiation or differentiate between high-LET and low-LET radiation.

> We know that the linear energy transfer (LET) is much higher for some radiations than for others. For those biological effects where LET matters, the rad unit must be modified to a unit that shows the greater effectiveness of one kind of radiation over another. A term has been introduced, the relative biological effectiveness, or RBE, to express this difference is effectiveness.

J. Gofman, Radiation and Human Health, supra, PX-1046, at 47. Defined in terms of a dose of gamma radiation producing a certain biological effect, e.g., chromosome lesions, cell-killing, etc., a rem represents the proportionate amount of other ionizing radiation that will produce the same biological effect, i.e., the same number of chromosome lesions, dead cells, etc. The specific proportion of one to the other, the RBE, varies according to type and energy of radiation, the type of cell exposed, the biological effect being studied, the total radiation dose, the dose rate, and other factors. N. Tsoulfanidis, supra, at 486. The same kind of radiation may have many RBE ratios.

As as general rule, biological damage increases as the amount of energy deposited per unit of distance traveled, the linear energy transfer (LET), increases. High-LET radiation, such as alpha particles, neutrons and fission fragments are often significantly more damaging than low-LET radiation, such as gamma ray photons, beta particles, and positrons, which have far less mass, and travel far greater distances, leaving less ionization in their wake. Id. J. Gofman, supra, at 26-29. In modern health physics, the concept of quality factor, or Q, is used to describe distinctions between radiations based upon linear energy transfer values. N. Tsoulfanidis, supra, at 486-87. While low-LET radiations may have a "Q" of 1, 5-MeV alpha particles may have a "Q" of 10 or even 20. Id.[82]

Whether expressed in terms of Q or RBE, the relative effects of different radiations is critical to accurate calculation of biological risk associated with radiation exposure. Once more, an example is instructive:

> A cattle rancher inhales a particle of fallout debris containing 1 pCi of radioactivity due to plutonium-239, an alpha emitter with a decay energy approximating 5 MeV. The particle becomes trapped in lung tissue.
>
> The alpha particles having a range in tissue of approx. 40 μm, the amount of energy delivered to the surrounding lung cells per hour may be calculated as follows:
>
> $$\frac{(3.7 \times 10^{-2}/s/p\,Ci)(54\ MeV)(1.602 \times 10^{-13}J/MeV)(3.6 \times 10^{3})}{(4/3)(4.0 \times 10^{-5})\,3(10^{3}kg/m^{3})}$$
>
> an amount equal to 39.7 rads/hour of α radiation to the surrounding tissue, probably less than a microgram of epithelial cells in the bronchial tubes. See N. Tsoulfanidis, supra, at 490-91; J. Gofman, supra, at 484.
>
> For many biological injuries, however, alpha particles of MeV range energy are assigned an RBE, or Q, of 10. Multiplying the absorbed dose by this factor yields a dose rate in rems per hour:
>
> (39.7 rads/hour) × RBE (10) = 397 rems/hour
>
> Thus the 3,970 ergs/gram of alpha energy bombarding the few cells nearest to the fallout particle has the biological effectiveness of 39,700 ergs/gram of low-LET beta or gamma radiation delivered to the same tissue. Ionizing radiation delivered at the rate to those cells likely would kill or seriously damage almost all of them. Fortunately, they represent an extremely tiny fraction of total lung tissue. Inhalation and retention of many more particles, however, could do far more damage to the bronchial linings.

Once the task of evaluating a particular exposure to radiation in terms of its relative biological effectiveness has been accom-

plished, the expression of dose in rem units is easily transferred or compared with other dose estimates expressed in rems. The risk arising from exposure to various radiations—alpha, beta, gamma or neutrons, among others, may be standardized and directly compared. A dose expressed in rems identifies a certain quantum of biological effect, regardless of source.[83]

In much of the literature, testimony and documentary evidence now before this court, however, doses of low-LET radiation expressed in rads are treated as equivalent to doses expressed in rems. Only as to alpha radiation is a distinction usually made. See Table II.

TABLE II.

Relation of Linear Energy Transfer (LET) and Type of Radiation to Quality Factor (QF)

Average LET in water (keV/μm)	Type of radiation	Quality factor
3.5 or less	X-rays, gamma rays, beta particles	1
7		2
	Neutrons (<10 keV)	3
23		5
53	Neutrons (>10 keV)	10
	Protons	1–10
	Alpha particles	1–20
175	Fission fragments, recoil nuclei	20

1 F. W. Whicker & V. Shultz, supra at 66.

To be fully effective, analysis of data and measurements concerning exposure of human beings to ionizing radiation must be made with particular reference to the units in which the information is expressed. Whatever unit is used, be it rad, roentgen, rem, or some fractional or multiple variant of these units, it describes the exposure to ionizing radiation or absorption of its tremendous energies by living tissue. See also Radiation Quantities and Units, ICRU Rep. No. 19 (July 1971), DX-1105.

B. Radiation Energy: Quantity vs. Quality

So far this discussion has dealt with the units of radiation measurement in terms of each other, and other measurements of radio-

activity, such as the curie, or the concept of half-life. It is important, however, to make at least a general comparison between the kinds and quantities of energy infused into biological systems by ionizing radiation and those imparted by more common, more familiar physical processes. It is one thing to define a unit called "rad" in terms of 100 other units of energy called "ergs," or an international unit known as the Joule.[84] How much energy does an erg represent, or a rad?

Perhaps the best comparison of amounts—and qualities—of energy can be drawn between ionizing radiation and heat. To do so, though, requires definition of one more unit describing energy:

> The calorie is the familiar unit in chemistry that describes energy transfers involving heat. One calorie is that amount of energy which will raise the temperature of one gram of water by one degree centigrade [or Celsius]. (This definition does change some at different temperatures of water, but for our purposes here we can neglect those small changes.)

> The best estimates are that approximately 400 rads of whole-body radiation, if delivered rapidly, are sufficient to cause 50% of the exposed humans to die within a period of days to weeks. This is the so-called acute radiation sickness. Is this a great deal of energy in heat terms? Some simple calculations show that it is not.

> Since 1 rad represents the absorption of 100 ergs per gram of tissue, it follows that 400 rads represents the absorption of 40,000 ergs per gram. The conversion factor from ergs to calories is 2.39×10^{-8}. Therefore,

$$40{,}000 \frac{\text{ergs}}{\text{gram}} \times 2.39 \times 10^{-8} \frac{\text{calories}}{\text{erg}} = 9.56 \times 10^{-4} \frac{\text{calories}}{\text{gram}}$$

> We can round this off to approximately 10^{-3} calories/gram (or 0.001 calories/gram).

> Biological tissue is quite comparable with water in the amount of heat required to raise its temperature by one degree centigrade [or Celsius]. So we shall say that the required

> amount is one calorie per gram for biological tissue too. Therefore, our 10^{-3} calories/gram from the absorption of 400 rads of ionizing radiation energy would be enough to raise the temperature of biological tissue by 0.0001 centigrade. Not much of a fever! We tolerate fevers of several degrees centigrade (not thousandths of a degree) in a variety of infectious diseases. Yet the amount of ionizing radiation that can kill half of the humans exposed to it, would—if converted first into heat—raise temperatures only by 0.001° centigrade.
>
> This points up the biologically deadly difference between energy in the form of heat versus the same amount of energy in the form of ionizing radiation. . . .
>
> The difference resides in the fact that the energy of ionizing radiation is not distributed the way the thermal energy of a fever is, the latter being distributed among all the molecules of a gram of tissue. Instead, the energy of ionizing radiation is transferred from photons to single electrons [or from charged alpha or beta particles], which in turn transfer all their energy to relatively few electrons in relatively few molecules. The transfer occurs in extremely concentrated fashion compared with the even diffusion of heat energy. Therefore, the energy delivered by ionizing radiation is energetic enough to break any chemical bond, even the strongest ones in living tissue. . . .

J. Gofman, Radiation and Human Health 52-53 (1981), PX-1046 (emphasis in original). It is not the quantity of energy penetrating the cells of the human body, but rather the quality of the energy, the nature of its interaction with cellular chemistry, which makes exposure to ionizing radiation an extraordinary hazard. As described in Part II, supra, alpha, beta and gamma radiations streak through matter at high energy and high speed, stripping electrons away from any chemical compound or individual molecule with which they come in close proximity or direct contact. The ionized molecules may reunite as before, with no detectable damage. They may also react with each other or with other molecules nearby, forming new and not necessarily useful compounds, reflecting a

temporary, or perhaps a permanent injury to the chemical structures originally present.

From the standpoint of biological injury, energy absorbed in the ionization of air, or a multitude of inanimate objects, is essentially meaningless. A glass of water which has been irradiated by alpha, beta or gamma rays poses no risk to health greater than any other water—unless, of course, it has become contaminated with radioactive material that would bombard internal organs with additional radiation if ingested. Far more important is the interaction of ionizing radiation with the tightly ordered, extremely complex and relatively fragile molecules of life.

Of particular concern is the effect of ionization on the lengthy and critically important strands of genetic material found in each living cell.

C. Ionizing Radiation and Chromosomes

At the interior of each living cell is found a nucleus of specialized proteins, enzymes, and other chemicals. The nucleus appears for most purposes to be the control center of the cell. It contains the long, spiralling molecules of DNA (deoxyribonuclecic acid), which carry encoded within their delicate patterns the entire genetic "blueprint" controlling the structure, composition and numberless chemical activities of the individual cell, the tissue in which it is found, and—somewhere within its strands—the remainder of the instructions followed by all of the other specialized cells that make up an incredibly detailed living organism. The DNA molecules are joined together in discrete units called genes, which in turn are grouped together in a series of genetic superstructures, called chromosomes. Each of the billions of cells in the human body, with the exception of red blood cells, contains an invariable normal count of 46 chromosomes within its nucleus. Within those chromosomes are carried more than 5 billion individual bits of genetic information, carefully stored in the chemical patterning of the DNA molecules. C. Sagan, Cosmos 276 (1980); see also J. Watson, The Molecular Biology of the Gene (2d ed. 1970).

The chromosomes themselves are seldom visible even under a strong microscope; either they show an amorphous structure indistinguishable from the surrounding material of the nucleus, or they appear as a threadlike cluster without apparent distinction. When a cell prepares to duplicate itself, to undergo the process called cell division or mitosis, the chromosomes condense and contract into tight individual units, each with its own unique shape and recently identifiable patterns of genes. See Figure 9. Hiroshima & Nagasaki, supra, at 312. Before the cell may replicate itself, the chromosomes within the nucleus must be duplicated. As best it can, the cellular chemistry sees to it that each of the 5 billion bits of stored chemical "knowledge" is meticulously copied. The existing DNA strands unravel and serve as models, as templates, for the formation of new, identical strands.

These most fundamental molecules of life, for their tremendous size and complexity, are among the most fragile and are the most irreplaceable of cellular chemicals.

Beginning with the work of Muller in 1927—many years before the structure of the DNA molecule was known or its function could be described, it was quickly discovered that ionizing radiation in all of its forms could effectively disrupt, impair or alter the genetic code. As we now know, the tracking of ionizing particles through the DNA strands will ionize them as well, breaking the fragile genetic text into disjoint fragments, or altering their chemical patterning and in doing so, changing or destroying the information imprinted therein. If luck prevails, a fragment of genetic material sliced away from the body of the chromosome may join back as before, with important information unaltered. An ionized fragment of a DNA chain may rejoin at a new site, as when two strands are severed and the fragments translocate, or when a "ring" chromosome is formed. A broken chromosome may not rejoin at all, resulting in a deletion of information from the genes which likely cannot be restored.

From Figure 9, it is notable that in each chromosome there is a central point at which the arms of material are joined. This is called a centromere, and is essential to normal replication of each

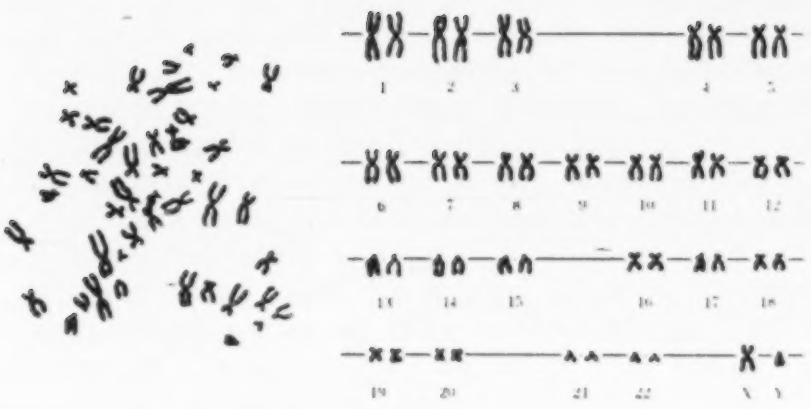


Figure 9. A normal male metaphase and its karyotype (46, XY).

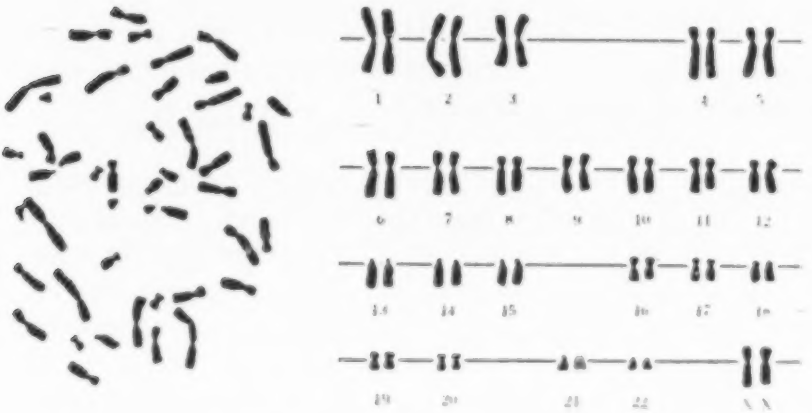
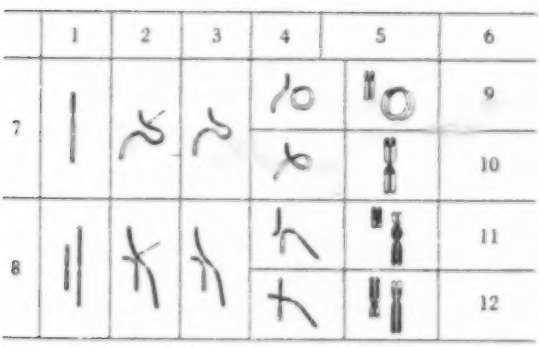


Figure 9. A normal female metaphase and its karyotype (46, XX).



1. Before irradiation
2. Irradiation
3. Break
4. Rejoining
5. (DNA synthesis) Metaphase chromosomes
6. Type of aberration
7. Intrachromosomal exchange
8. Interchromosomal exchange
9. A ring (r) with an acentric (ace)
10. Pericentric inversion (inv)
11. A dicentric with an acentric (ace)
12. Reciprocal translocation (rep. t)

Fig. 10. Mechanism and types of radiation-induced chromosome aberration.

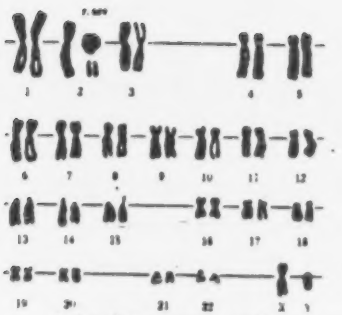
chromosome. The haphazard reordering occasioned by radiation-caused ionizations may result in chromosomes with two centromeres, or no centromere, or may otherwise prevent the normal operation of the centromere in the process of cell division. See Figs. 10 and 11.

Besides the DNA molecules in the chromosomes, ionizing radiation may easily damage or destroy any other vital molecule or key structure within the cell which is necessary for normal function.

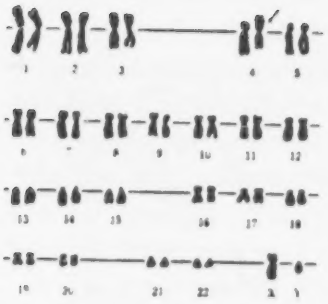
Following the incursion of ionizing radiation into living tissue, the ultimate responses of the individual cells may be grouped into four main categories: (1) ionizing radiation having done no permanent damage, any fractured molecules are repaired or replaced, and normal cell function continues; (2) radiation having inflicted lethal damage upon vital features of the cell's inner machinery, the cell dies, hopefully to be replaced by a faithful copy produced from an undamaged cell nearby; (3) radiation having damaged the cell's reproductive capacity, but not to lethal extent, the cell continues to function normally or abnormally until its death without further mitosis; and (4) radiation having done permanent damage to the cell, esp. its genetic information, the cell continues to function and reproduce, but with some abnormality in either or both respects. Tr. at 2774-2775 (testimony of Dr. Karl Z. Morgan).

The first outcome of radiation exposure is obviously the most desirable: no damage. The third outcome, while perhaps disruptive of bodily function if experienced in a significant fraction of the cell population, presents no long-term threat of uncontrolled cell proliferation, i.e., cancer. The second outcome is most serious, perhaps, in cases of acute high-dose exposure, where significant rates of cell death may disrupt the operation of vital tissues and organs. In the long term, however, a dead cell cannot reproduce, abnormally or otherwise. The phenomenon of cell-killing by higher dose rates of radiation may in fact explain the apparent decrease in rate of cancer incidence per rad at high doses. A greater fraction of the affected cells may be destroyed, leaving proportionately fewer to evolve and later proliferate as cancer cells.

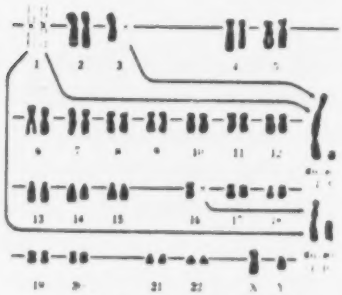
In terms of long-term effects on health, the fourth category of cell response is certainly the most critical, and likely the least



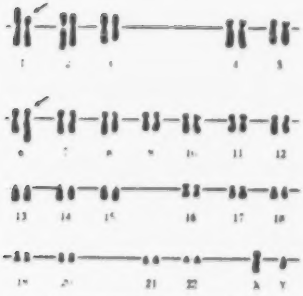
A ring chromosome (r) with an accompanying acentric (ace).



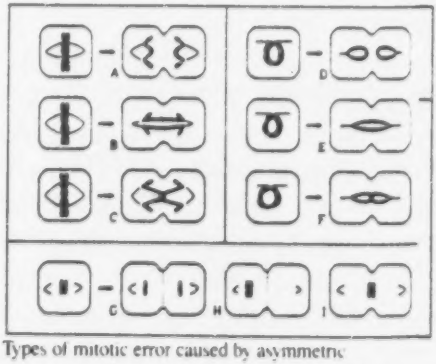
A pericentric inversion (inv).



Two dicentrics (dic) and their accompanying acentrics (ace).



A reciprocal translocation (t).



Types of mitotic error caused by asymmetric chromosome exchanges (*A, D, G*: Normal divison; *B, E*: Chromosome bridge; *C, F*: Chromosome interlocking; *H*: Unequal segregation of chromosomes; *I*: Chromosome lagging)

Fig. 11. from: Hiroshima and Nagasaki, supra, at 314.

probable. Tr. at 2775. No one at this point knows the exact mechanism, or mechanisms, by which the cancerous proliferation of abnormal cells is initiated or promoted within the human body. Perhaps a single ionization of a vital gene within a single cell starts an organism down the path to cancer or leukemia. Perhaps it is two strategic disruptions of the chromosomes, or three, that cause cells to grow and reproduce where there is no need for them. Perhaps, the control mechanism which fails in carcinogenesis is not genetic, or is a combination of genetic and other cellular mechanisms, or it may be that perhaps cancer is the product of a synergistic interaction between radiation, chemicals, or interference with cellular and genetic processes by pathogenic viruses which have gone unidentified. It may even take a community of damaged cells working in concert to produce a cancer. No one really knows.

What is known is that ionizing radiation in its various forms has been causally linked to several different categories of somatic effects, i.e., biological consequences which manifest themselves in the health of the person actually exposed, which include cancer.

> When we refer to radiation as a cause, we do not mean that it causes every case of cancer or leukemia. Indeed, the evidence we have indicating radiation in the causation of cancer and leukemia shows that not all cases of cancer are caused by radiation. Second, when we refer to radiation as a cause of cancer, we do not mean that every individual exposed to a certain amount of radiation will develop cancer. We simply mean that a population exposed to a certain dose of radiation will show a greater incidence of cancer than that same population would have shown in the absence of the added radiation.
>
> * * * *
>
> The fact that radiation and other known carcinogens seem to add to the number of cancers already occurring in people, rather than to produce new varieties of cancer, suggests, along with other evidence, that the process of carcinogenesis is one form of biological reaction by organized living systems to certain classes of biological insults. . . .

J. Gofman, Radiation and Human Health 54-55, 59 (1981), PX-1046.

There are also risks of serious genetic effects. Future generations of offspring may be congenitally injured by flawed information transmitted by irradiated, damaged chromosomes. Each cell carries the complete genetic instructions for the construction and operation of the entire human body. It is likely of little consequence of the arm of one chromosome which determines the color of the eyes, for example, is deleted by radiation passing through a cell in the lining of the stomach. Deletion of the same chromosome in the germ cells of the reproductive system, however, may visibly affect a child yet unborn.[85]

Teratogenic effects of radiation, i.e., injury to unborn children by exposure of pregnant women to radiation, see e.g., BEIR-III Report, 477-93 (1980), DX-1025; Gofman, supra, at 707-759; Hiroshima and Nagasaki, supra, at 214-233, may also prove extremely important.

The most significant somatic effect reflected in the general population, of course, is the induction of a variety of forms of cancer and leukemia. Only chronic lymphatic leukemia and a very few solid tumors, such as cancer of the prostate, have escaped direct causal connection to ionizing radiation. In almost all major categories of cancer, including lung and breast cancer, radiation exposure has been identified to an increased risk of illness. See e.g., UNSCEAR Report (1977) PX-706/DX-605, Annex G. ¶¶ 1-332, at 361-423, and references cited therein.

Apart from cancer and leukemia, the most pronounced somatic effects of radiation exposure, especially at doses greater than 25 rads received all at once or over a brief period, are the symptoms and injuries associated with acute radiation illness syndrome.

D. Health Effects of Acute Radiation Exposure

The use of the atomic bomb upon the populations of Hiroshima and Nagasaki, Japan presented a tragic opportunity for the detailed study of illnesses experienced by an entire population, young and old, men and women, following varying degrees of radiation ex-

posure. This data, combined with information generated over the years by unfortunate experiments involving too much radiation, provides a fairly complete picture of the short-term effects of acute doses greater than 25 rads. See e.g., Hiroshima and Nagasaki, supra, at 107-185; S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶¶ 12.90-12.140, at 575-590 (3d ed. 1977), DX-1242. The clinical effects of acute radiation exposure are summarized in Table 12.

Though several of the witnesses in this action testified concerning symptoms such as reddening of skin and loss of hair (epilation) which are characteristic of acute radiation illness syndrome, no one in the present 24 cases has sought an award of damages in compensation for acute radiation injuries. The testimony was offered for a different purpose.

See Part IX(D), infra. Besides being notable for the dose ranges at which specific effects occur, the symptoms and injuries reflected in acute radiation illness are important herein for historical reasons; on a number of occasions the operational treatment of offsite radiation safety at the Nevada Test Site seemed to have been geared almost entirely to avoidance of only these most visible—and traceable—effects. See Part VIII, infra.

Other somatic effects traced to radiation exposures include loss of fertility, development of cataracts, and premature aging. Id. DX-1025, at 493-505, as well as permanent scarring and other persistent effects of acute radiation injuries. See e.g., Hiroshima and Nagasaki, supra, at 187-251.

E. Radiation Dosage and Dose Rates

The illness syndrome accompanying acute radiation exposures clearly establishes that the rate at which an accumulated dose of radiation is received may have a material impact on the biological consequences of exposure. Except for narrowly perceptible changes in blood cell counts and characteristics which can now be detected after short-term exposures of 1 rad or less, the symptoms of acute illness indeed reflect the presence of a "threshold" level of exposure below which they do not appear.

Table 12.

SUMMARY OF CLINICAL EFFECTS OF ACUTE IONIZING RADIATION DOSES

Range	0 to 100 rems Subclinical range	100 to 1,000 rems Therapeutic range			Over 1,000 rems Lethal range	
		100 to 200 rems	200 to 600 rems	600 to 1,000 rems	1,000 to 5,000 rems	Over 5,000 rems
		Clinical surveillance	Therapy effective	Therapy promising	Therapy palliative	
Incidence of vomiting	None	100 rems: infrequent 200 rems: common	300 rems: 100%	100%	100%	
Initial Phase						
Onset	—	3 to 6 hours	½ to 6 hours	¼ to ½ hour	5 to 30 minutes	Almost immediately**
Duration	—	< 1 day	1 to 2 days	< 2 days	< 1 day	
Latent Phase						
Onset	—	< 1 day	1 to 2 days	< 2 days	< 1 day*	Almost immediately**
Duration	—	< 2 weeks	1 to 4 weeks	5 to 10 days	0 th 7 days*	
Final Phase						
Onset	—	10 to 14 days	1 to 4 weeks	5 to 10 days	0 to 10 days	Almost immediately**
Duration	—	4 weeks	1 to 8 weeks	1 to 4 weeks	2 to 10 days	
Leading organ	Hematopoietic tissue				Gastrointestinal tract	Central nervous system
Characteristic signs	None below 50 rems	Moderate leukopenia	Severe leukopenia; purpura; hemorrhage; infection. Epilation above 300 rems		Diarrhea, fever, disturbance of electrolyte balance	Convulsions, tremor, ataxia, lethargy
Critical period post exposure	—	—	1 to 6 weeks		2 to 14 days	1 to 48 hours

No. C 79-0515-J

Therapy	Reassurance	Reassurance, hematologic surveillance	Blood transfusion, antibiotics	Consider bone marrow transplantation	Maintenance of electrolyte balance	Sedatives
Prognosis	Excellent	Excellent	Guarded	Guarded	Hopeless	
Convalescent period Incidence of death	None None	Several weeks None	1 to 12 months 0 to 90%	Long 90 to 100%	— 100%	
Death occurs within	—	—	2 to 12 weeks	1 to 6 weeks	2 to 14 days	< 1 day to 2 days
Cause of death	—	—	Hemorrhage, infection		Circulatory collapse	Respiratory failure; brain edema

*At the higher doses within this range there may be no latent phase.

**Initial phase merges into final phase, death usually occurring from a few hours to about 2 days; this chronology is possibly interrupted by a very short latent phase.

No. C 79-0515-J

Where long-term effects are concerned, however, the importance of dose rate seems greatly diminished. In 1980, the Committee on Biological Effects of Ionizing Radiation of the National Research Council (the "BEIR-III Committee") reported that "dose rate may affect the risk of cancer induction, but believes that the information available on man is insufficient to adjust for it." BEIR-III Report, supra, DX-1025, at 3. Other researchers are far more adamant on the subject. See J. Gofman, Radiation and Human Health, supra, PX-1046, at 404-407.

If, in fact, cancer and leukemia result from some genetic injury induced by radiation, or chemical substances,—or both—the case of the proposition that low rate of exposure greatly reduces risk is weakened by the observation made in the earliest research that radiation injuries to genes and chromosomes appear to be cumulative, except to the limited extent that they are correctly repaired by processes within the cell. While the extent of radiation injury to cells inflicted at "high" dose rates may perceptibly affect the functioning of the organism more dramatically than a series of "low" doses imparted to cells over a period of time, injury may nevertheless result. At the level of the individual cell, ionization is ionization, and a linear energy transfer is a linear energy transfer. Id. PX-1046, at 42, 404-07. If a single alpha particle does carcinogenic damage to the genetic machinery of a cell, it may be irrelevant whether additional particles crash through the cell chemistry or not. Indeed, the 1980 Report of the BEIR-III Committee, quoted above, observes that "[t]here appear to be mechanisms. . . pertaining especially to exposure to high-LET radiation, that increase the observed effect per unit dose when the dose rate is reduced." BEIR-III Report, supra, DX-1025, at 3. The failure of the human epidemiological studies to persuasively identify a "threshold" dose below which the risk of cancer is not at all increased lends additional support to the view that even at low doses, critical biological injuries accumulate. See also Part IX(C), infra.

F. Radiation Exposure: Internal, External, Whole-Body, Partial-Body

Prior sections of this opinion discuss and emphasize the fact that the potential for radiation injury from nuclear fallout debris is not

limited to the dose received from gamma-emitting (or beta-emitting) radionuclides outside the body. There also exists the potential for serious exposure from radioactive debris inhaled, ingested or absorbed into the human body from contaminated food, water, milk, or dust. At the cellular level, however, the distinction between external and internal dose disappears. The amount of chemical disruption that a cell experiences from whatever source of radiation in any direction or at any distance is the important consideration. The phenomenon of internal exposure simply allows shorter-range alpha and beta particles greater access to more sensitive cells and tissues.

An important distinction must be drawn however, between radiation dose to the whole body and estimated radiation doses to specific organs. The biological impact of 300 rads absorbed by the skin is distinctly different in nature and severity from the impact of a 300-rad whole-body dose. Where whole-body exposure is concerned the absorbed energy is being visited upon nearly every gram of living matter in the body. A partial-body dose absorbed by a particular organ, such as the thyroid, the bone marrow, or the lung may be of considerable importance to the organ involved, but signifies far less relative damage to other organs and tissues.

In reviewing articles, studies, documents and testimony, considerable error in risk estimation may be avoided simply by paying heed to whether exposure and dose are being expressed in terms of the whole body or a particularized organ or system.

G. Other Sources of Radiation Exposure

Fallout from atmospheric nuclear testing in Nevada is only one of a collection of sources of exposure to ionizing radiation, both man-made and naturally occurring. First, every person living on the earth receives some amount of radiation from the natural sources generally blanketed under the term "background" radiation. Natural background radiation derives from a number of sources: naturally occurring heavy elements, such as uranium, thorium, radium, radon, and polonium, and a few lighter radionuclides which are readily incorporated into living tissue in trace amounts, e.g., potassium-40 and carbon-14. Natural radioactivity

is all around us, in soil, in building materials, and in trace amounts in meat, vegetables, fruits, grains and drinking water.

Additional background exposure is traced to cosmic rays, high-energy gamma rays and atomic particles which rain down from the sun through the atmosphere. People living at higher altitudes receive slightly more radiation than those who live at sea level, as do people whose occupations take them on frequent airline trips. See UNSCEAR Report (1977), PX-706/DX-605 at ¶¶ 213, 218-236, at 81-86; see also id., at 35-114 and references cited therein.

The most prominent source of man-made radiation exposure is the use of X-rays and radioisotopes in medical diagnosis and treatment. A significant dose of X-rays may be received from older or poorly maintained equipment. A number of current efforts are addressed to the accurate evaluation of risks arising from present methods and practices using radiation in medicine.

In addition to these nearly universal sources, some additional exposure is attributed to industrial processes using radiation, some consumer goods and the growth of the nuclear power industry. Particularly in reference to the latter, a pattern of considerable numbers of low-dose occupational exposures has developed. Table 13, extracted from the 1980 Report of the BEIR-III Committee, briefly summarizes the source and extent of commonplace radiation exposure to the general public.

Even in terms of exposure to radioactive fallout from nuclear tests, Nevada operations were only one source. The United States tested a number of higher-yield atomic and thermonuclear weapons on its Pacific Test Range between 1946 and the effective date of the Nuclear Test Ban Treaty in 1962. The weapons-testing programs of the U.S.S.R. and other nations have also made significant contributions to the worldwide fallout burden, with detectable impact on low-level exposure rates in Utah. At least one recent study identifies a significant portion of the plutonium fallout residue remaining in Utah soils to worldwide (thermonuclear) fallout rather than debris from tests in Nevada. See P. Krey and H. Beck, "The Distribution Throughout Utah of ^{137}Cs and $^{239+240}Pu$ from

TABLE 13.
Annual Dose Rates from Important Significant Sources of Radiation Exposure in United States.

Source	Exposed Group		Body Portion Exposed	Average Dose Rate, mrems/yr	
	Description	No. Exposed		Exposed Group	Prorated over Total Population
Natural background					
Cosmic radiation	Total population	220×10^6	Whole body	28	28
Terrestrial radiation	Total population	220×10^6	Whole body	26	26
Internal Sources	Total population	220×10^6	Gonads	28	28
			Bone marrow	24	24
Medical x rays					
Medical diagnosis	Adult patients	105×10^6/yr	Bone marrow	103	77
Medical personnel	Occupational	195,000	Whole body	300 – 350[a]	0.3
Dental diagnosis	Adult patients	105×10^6/yr	Bone marrow	3	1.4
Dental personnel	Occupational	171,000	Whole body	50 – 125[a]	0.05
Radiopharmaceuticals					
Medical diagnosis	Patients	10×10^6 to 12×10^6/yr	Bone marrow	300	13.6
Medical personnel	Occupational	100,000	Whole body	26 – 350	0.1
Atmospheric weapons tests	Total population	220×10^6	Whole body	4 – 5	4 – 5
Nuclear industry					
Commercial nuclear power plants (effluent releases)	Population within 10 mi	$<10 \times 10^6$	Whole body	<< 10	<< 1
Commercial nuclear power plants (occupational)	Workers	67,000	Whole body	400[b]	0.1
Industrial radiography (occupational)	Workers	11,250	Whole body	320	0.02
Fuel processing and fabrication (occupational)	Workers	11,250	Whole body	160	0.01
Handling byproduct materials (occupational)	Workers	3,500	Whole body	350	0.01
Federal contractors (occupational)	Workers	88,500	Whole body	~250	0.1

TABLE 13. (continued)

Source	Exposed Group		Body Portion Exposed	Average Dose Rate, mrems/yr	
	Description	No. Exposed		Exposed Group	Prorated over Total Population
Naval nuclear propulsion program (occupational)	Workers	36,000	Whole body	220	0.04
Research activities					
Particle accelerators (occupational)	Workers	10,000	Whole body	Unknown	<<1
X-ray diffraction units (occupational)	Workers	10,000 – 20,000	Extremities and Whole body	Unknown	<<1
Electron microscopes (occupational)	Workers	4,400	Whole body	50 – 200	0.003
Neutron generators (occupational)	Workers	1,000 – 2,000	Whole body	Unknown	<<1
Consumer products					
Building materials	Population in brick and masonry buildings	110×10^6	Whole body	7	3 – 4
Television receivers	Viewing populations	100×10^6	Gonads	0.2 – 1.5	0.5
Miscellaneous					
Airline travel (cosmic radiation)	Passengers	35×10^{6c}	Whole body	3	0.5
	Crew members and flight attendants	40,000	Whole body	160	0.03
Airline transport of radioactive materials	Passengers	7×10^{6d}	Whole body	~0.3	0.01
	Crew members and flight attendants	40,000	Whole body	~3	<0.001

[a] Based on personnel dosimeter readings; because of relatively low energy of medical x rays, actual whole-body doses are probably less.
[b] Average dose rate to the approximately 40,000 workers who received measurable exposures was 600 – 800 mrems/yr.
[c] Total number of revenue passengers per year is 210×10^6; however, many of these are repeat airline travelers.
[d] About one in every 30 airline flights includes the transportation of radioactive materials; assuming 210×10^6 passengers per year (total), approximately 7×10^6 would be on flights carrying radioactive materials.

from: the BEIR-III Report, supra, DX-1025, at 66-67 (1980).

Nevada Test Site Detonations," EML-400 (Nov. 1981), DX-1108, at 33, tbl. 6.[86]

V. DISCRETIONARY FUNCTION

At the end of the trial the United States moved to dismiss this matter on the grounds that the actions of the United States of which plaintiffs complain are insulated from complaint by the discretionary function exception found in the Tort Claims Act.

28 U.S.C.A. 2680(a) (1976) states:

> The provisions of this chapter and section 1346(b) of this title shall not apply to—
> (a) Any claim based upon an act or omission of an employee of the government, exercising due care, in the execution of a statute or regulation, whether or not such statute or regulation be valid, or based upon the exercise or performance or the failure to exercise or perform a discretionary function or duty on the part of a federal agency or an employee of the government, whether or not the discretion involved be abused. [emphasis added.]

The United States first raised this question during the preliminary stages of this case. At that time, this court denied the motion, awaiting the development of a full and complete record.

The history of the discretionary function exception, its rationale, and cases construing the exception were discussed in the court's opinion found at Allen v. United States, 527 F. Supp. 476 (D. Utah 1981).

The matters discussed in that opinion are equally pertinent at this stage of the proceeding. At this stage we do know enough to determine whether the acts complained of were discretionary and thus beyond the jurisdiction of this court. The early opinion provides the analytical framework against which we may now view the actions of the United States as developed in the full record.

In Allen, this court then states:

The discretionary function exception to the Federal Tort Claims Act, 28 U.S.C. § 2680(a), has been the subject of extensive litigation and of professional and scholarly comment. See e.g., Reynolds, "The Discretionary Function Exception of the Federal Tort Claims Act," 57 Georgetown Law Journal 81 (1968); Annot., 37 A.L.R. Fed. 537 (1978); Annot., 36 A.L.R. Fed. 240 (1978); Annot., 35 A.L.R. Fed. 481 (1977); Annot., 99 A.L.R.2d 1016 (1965). Of the exceptions to the Government's waiver of sovereign immunity under the Federal Tort Claims Act, the discretionary function exception has by far the greatest potential for repeated and varied application. The other exceptions bar litigation by certain classes of plaintiffs or the adjudication of specific categories of claims. The discretionary function exception compels an examination of the intrinsic nature of the Government's conduct, no matter who the plaintiff is or what interest the plaintiff asserts has been injured by that conduct.

Read broadly, the discretionary function exception may easily swallow the rule; the stopping of a government truck at a highway stop sign involves choice, judgment, assessment of risks—discretion in the broadest sense. Clearly the courts must sort the intrinsically discretionary from the truly operational if the Federal Tort Claims Act is to have any meaningful application at all.

The initial outline of the reach of the exception was traced by the United States Supreme Court in Dalehite v. United States, 346 U.S. 15, 73 S.Ct. 956, 97 L.Ed. 1427 (1953), involving claims arising from the cataclysmic explosion of shiploads of government fertilizer at Texas City, Texas. In Dalehite, the Supreme Court held the plaintiffs' claims against the United States for negligent planning and handling of the fertilizer shipment to be encompassed within the discretionary function exception. Justice Reed couched this finding in broad terms:

"It is unnecessary to define, apart from this case, precisely where discretion ends. It is enough to hold, as we do, that the 'discretionary function or duty' that cannot form a basis for suit under the Tort Claims Act includes more than the initiation of programs and activities. It also includes determinations made by executives or administrators in establishing plans, specifications or schedules of operations. Where there is room for policy judgment and decision there is discretion." Id., 346 U.S. at 35-36, 73 S.Ct. at 967-68 (emphasis added).

Since Dalehite the federal courts have struggled repeatedly to formulate a principled analysis of governmental conduct that will effectively guide the application of the discretionary function exception, see, e.g., Blessing v. United States, 447 F. Supp. 1160 (E.D.Pa. 1978), and cases cited therein; Jackson v. Kelly, 557 F.2d 735, 737 (10th Cir. 1977), while remaining consistent with the broad language of Dalehite. See Barton v. United States, 609 F.2d 977, 979 (10th Cir. 1979) ("The basic authority is Dalehite v. United States . . . ."). No "precise litmus paper test," Payton v. United States, 636 F.2d 132, 143 (5th Cir. 1981), has yet emerged. See e.g., Baird v. United States, 653 F.2d 437, 441-42 (10th Cir. 1981).

Instead, the courts have looked to the policies underlying the discretionary function exception and have balanced those against the policies served by the Federal Tort Claims Act. As the United States Court of Appeals for the Fifth Circuit pointed out in Payton v. United States, 636 F.2d 132 (5th Cir. 1981), "The crux of the concept embodied in the discretionary function exception is that of separation of powers." Id. at 143 (footnote omitted). Judge Becker in Blessing v. United States, 447 F. Supp. 1160, 1170 (E.D.Pa. 1978) skillfully elaborates on this notion:

"Read as a whole and with an eye to discerning a policy behind this provision, it seems to us only to articulate a policy of preventing tort actions from becoming a vehicle for judicial interference with decisionmaking that is properly ex-

ercised by other branches of the government and of protecting 'the Government from liability that would seriously handicap efficient government operations,' United States v. Muniz, 374 U.S. 150, 163 [83 S.Ct. 1850, 1858, 10 L.Ed.2d 805]. . . Statutes, regulations, and discretionary functions, the subject matter of § 2680(a), are, as a rule, manifestations of policy judgments made by the political branches. In our tripartite governmental structure, the courts generally have no substantive part to play in such decisions. Rather the judiciary confines itself. . . to adjudication of facts based upon discernible objective standards of law. In the context of tort actions,. . . these objective standards are notably lacking when the question is not negligence but social wisdom, not due care but political practicability, not reasonableness but economic expediency. Tort law simply furnishes an inadequate crucible for testing the merits of social, political, or economic decisions." Id., 447 F. Supp. at 1170 (footnotes omitted and emphasis added).

This concern for the non-justiciability of questions of political, social or economic policy, a concern long-recognized under traditional separation of powers principles, finds some reflection in the legislative history of the discretionary function exception, see e.g., Hearings on H.R. 5373 and 6463, House Committee on the Judiciary, 77th Cong., 2d Sess., at 29 (1942) (Statement of Francis M. Shea), and in the Supreme Court's initial construction of the exception in Dalehite v. United States, supra, 346 U.S. at 34, 73 S.Ct. at 967 ("The 'discretion' protected by the section. . . is the discretion of the executive or administrator to act according to one's judgment of the best course, a concept of substantial historical ancestry in American law" [footnote omitted]). In Dalehite, Justice Reed attempted to define the limits of protected discretion through reference to the "planning" level as opposed to the "operational" level of government activity: conduct at the planning level is discretionary and therefore immune, conduct at the operational level is not. Dalehite, however, gives little transferable guidance in determining

where "planning" stops and "operations" begin. Some light was shed upon the subject by the Supreme Court in its subsequent decision in Indian Towing Co. v. United States, 350 U.S. 61, 76 S.Ct. 122, 100 L.Ed. 48 (1955), involving alleged negligence by the Coast Guard in the operation of a coastal lighthouse. In Indian Towing, Justice Frankfurter's opinion for the majority distinguished Dalehite and held the Government liable for its alleged negligence:

"The Coast Guard need not undertake the lighthouse service. But once it exercised its discretion to operate a light on Chandeleur Island and engendered reliance on the guidance afforded by the light, it was obligated to use due care to make certain that the light was kept in good working order: and, if the light did become extinguished, then the Coast Guard was further obligated to use due care to discover this fact and to repair the light or give warning that it was not functioning. If the Coast Guard failed in its duty and damage was thereby caused to petitioners, the United States is liable under the Tort Claims Act.

* * * *

The differences between this case and Dalehite need not be labored. The governing factors in Dalehite sufficiently emerge from the opinion in that case."

Id., 350 U.S. at 69, 76 S.Ct. at 126 (footnote omitted).

Certainly the details of lighthouse operation involved questions requiring levels of choice, judgment—discretion in the broad sense.

In Rayonier, Inc. v. United States, 352 U.S. 315, 77 S.Ct 374, 1 L.Ed.2d 354 (1957) again the Supreme Court considered Government liability for actions involving some degree of independent judgment and held the Government to be liable without even discussing the discretionary function exception. In Rayonier, the plaintiffs were damaged as a result of a fire that raged out of control because of the alleged negligence in the

firefighting strategy and tactics of federal officials. The allegations included allegations of negligence in the "planning" stages of the federal fire control effort. Rejecting language from Dalehite that found no private cause of action for governmental negligence in firefighting, the Court construed the Federal Tort Claims Act's waiver of sovereign immunity to encompass the plaintiff's claims. The decisions of the federal officials in Rayonierseem at face value no less discretionary than some of those immunized in Dalehite: exercising judgment in withdrawing firemen from a location seems no more "ministerial" or "operational" than exercising judgment in deciding to fill paper bags with ammonium nitrate fertilizer at a given temperature and humidity.

Some lower federal courts, while treating the Dalehite case as the leading opinion on the scope of 28 U.S.C. § 2680(a), have cautiously observed the apparent narrowing of Dalehite by Indian Towing and Rayonier. See Relf v. United States, 433 F. Supp. 423, 427 (D.D.C. 1977). The "planning/operational" distinction offered by Justice Reed in Dalehite has grown increasingly ineffective in harmonizing the results of subsequent cases. See Hatahley v. United States, 351 U.S. 173, 76 S.Ct. 745, 100 L.Ed. 1065 (1956); United States v. Muniz, 374 U.S. 150, 83 S.Ct. 1850, 10 L.Ed.2d 805 (1963); compare, e.g., Ashley v. United States, 215 F. Supp. 39, 45-46 (D.Neb. 1963) (field decision on how to handle a troublesome bear in a National Park held "discretionary"), affirmed, 326 F.2d 499 (8th Cir. 1964), with Downs v. United States, 522 F.2d 990 (6th Cir. 1975) (FBI agent's decision on how to handle an airplane hijacking not "discretionary").

In Smith v. United States, 375 F.2d 243 (5th Cir. 1967), the Fifth Circuit discarded the "planning/operational" distinction in favor of an approach looking to the policies underpinning the discretionary function exception and to the nature of the discretion involved in each case:

"If the Tort Claims Act is to have the corpuscular vitality to cover anything more than automobile accidents in which

government officials were driving, the federal courts must reject an absolutist interpretation of Dalehite, and that interpretation is rejected by Indian Towing and especially by Rayonier. . . . Cases under the Act therefore put courts to the question of what sorts of decisions can be classified as resulting from discretion within the meaning of § 2680(a). It is not a sufficient defense for the government merely to point out that some decisionmaking power was exercised by the official whose act was questioned. Answering these questions, a difficult process, is not aided by importation of the planning stage-operational stage standard as argued for— . . . Such a distinction is specious. It may be a makeweight in easy cases where of course it is not needed, but in difficult cases it proves to be another example of a distinction 'so finespun and capricious as to be almost incapable of being held in mind for adequate formulation.' Mr. Justice Frankfurter for the Court in Indian Towing, supra, 350 U.S. at 68 [76 S.Ct. at 126]. . . Such non-statutory 'aids' to construction tend to obscure, to limit, or even to replace the standards whose meaning they are supposed to clarify. . . It must be remembered that the question at hand here is the nature and quality of the discretion involved in the acts complained of."

Id., 375 F.2d at 246 (emphasis added, footnote and citations omitted). In Smith, the plaintiff sought damages for the failure of the Government to prosecute persons allegedly injuring his business through boycotts and picketing. Recalling that court's earlier conclusion in United States v. Cox, 342 F.2d 167, 171 (5th Cir. 1965) that "as an incident of the constitutional separation of powers, . . . the courts are not to interfere with the free exercise of the discretionary powers of the attorneys of the United States in their control over criminal prosecutions," Judge Goldberg held 28 U.S.C. § 2680(a) to apply:

"We therefore hold that § 2680(a) exempts the government from liability for exercising the discretion inherent in the prosecutorial function of the Attorney General, no matter whether these decisions are made during the investigation or

prosecution of offenses. See United Staes v. Faneca, 332 F.2d 872 (5th Cir. 1964). Another holding could diffuse the government's control over policies committed to it by the Constitution, and irrationally concentrate political responsibility in fortuitous lawsuits.

In Payton, the plaintiffs alleged that the United States Board of Parole and the Bureau of Prisons negligently released on parole a dangerous convict who subsequently committed additional murders against the plaintiffs' decedents, resulting in the claim for damages for wrongful death. While the decision to release the prisoner in question certainly involved the exercise of discretion in the classic sense, the Court, led by Judge Fay, denied immunity under § 2680(a). While the Court would extend the discretionary function exception to insulate the Parole Board's formulation of its basic policies and parole guidelines, it extended immunity no farther:

"The choices involved in applying the guidelines and releasing a particular person are of another sort. Whether characterized as "operational," "day-to-day" or by some other label, they do not achieve the status of a basic policy evaluation and decision. Such decisions, if negligent, are not protected by section 2680(a)." Id. at 147.

The Fifth Circuit's limitation of the discretionary function exception to the protection of basic social, political and economic policy decisions under traditional separation of powers principles has found reflection in the analysis applied by other courts.

The United States Court of Appeals for the Third Circuit in Griffin v. United States, 500 F.2d 1059 (3d Cir. 1974), in determining the Government's liability for an administrative decision releasing a batch of live polio virus vaccine which turned out to be hazardous and resulted in injury to the plaintiffs, looked to the public policy content of the decision complained of. Rejecting the Government's broad assertion

of discretionary function immunity. Judge Rosenn explained the Court's analysis of the issue, commencing with Dalehite:

"The decisions held discretionary in Dalehite involved, at minimum, some consideration as to the feasibility or practicability of Government programs. . . Such decisions involved considerations of public policy, calling for a balance of such factors as cost of Government programs against potential benefit. . . Where decisions have not involved policy judgments as to the public interest, the courts have not held the decisions to be immune from judicial review. . . To determine the applicability of the discretionary function exception, therefore, we must analyze not merely whether judgment was exercised but also whether the nature of the judgment called for policy considerations."

Id., 500 F.2d at 1064 (emphasis added and citations omitted). Under Griffin, an administrative decision, though couched in the complex considerations of scientific, professional or highly technical judgement, is not "discretionary" within the meaning of 28 U.S.C. § 2680(a) unless it additionally embodies political, social or economic policy judgments traditionally insulated from judicial scrutiny by the separation of powers doctrine.

"Whatever else § 2680(a) may do, its discretionary function exception prevents this diffusion of governmental power into private hands. The United States is immune from liability in the present case not because of the mere fact that government officials made choices, but because the choices made affected the political (not merely the monetary) interests of the nation. The Act is intended to spread monetary losses in certain cases among the taxpayers; it is not intended to affect the distribution of political responsibility."

Id., 375 F.2d at 248 (emphasis added). In Smith, Judge Goldberg outlines the construction of § 2680(a) in light of its fundamental purpose, preservation of the transitional constitutional separation of powers. This form of analysis of the discretionary function exception has been propounded in

useful detail by another Fifth Circuit panel in Payton v. United States, 636 F.2d 132 (5th Cir. 1981). The Payton analysis seeks a pragmatic balancing of private and governmental interests "without the conclusory application of labels." Id., 636 F.2d 143-44.

"Considering initially the injured party, the court should review the nature of the loss imposed by the governmental injury. The more serious, in terms of physical or mental impairment, and isolated the loss the closer the question becomes as to whether the individual can be expected to absorb the loss as incident to an acceptable social or political risk of governmental activities. Other factors to be weighed are the expectation of the public or the injured party and the nature of the reliance, whether based upon a consistent level of governmental activity or upon the party's lack of foresight. However deep analysis of these considerations would be more significant in the negligence phase of the court's determinations. A further point of consideration might be the existence of alternative remedies or compensations for the injured party, since the dearth of such alternatives was a primary reason for the enactment of the [Federal Tort Claims Act]."

Id., 636 F.2d at 144 (footnotes omitted). The interests of the injured party are of particular concern, according to Payton, because "the spread of monetary losses among the taxpayers is the principle concern" of the Federal Tort Claims Act. Id. Payton approaches the countervailing interests of the Government as follows:

"Looking to the government's interest, the trial court would need to assess the nature and quality of the governmental activity causing the injury. Smith v. United States, 375 F.2d 243, 246 (5th Cir. 1967). This could be done by examining the agency's guidelines, or procedures in the area, see, e.g., Griffin v. United States, 500 F.2d 1059, 1064-68 (3d Cir. 1974), and determining the administrative level at which the injurious activity took place. See, e.g., Hendry v.

United States, 418 F.2d 774, 783 (2d Cir. 1969). Along these lines, the court must determine if the allegations attack the rules formulated by the agency or merely their application. Dalehite v. United States, 346 U.S. at 27, 35 [73 S.Ct. at 963, 967]; Hendry v. United States, 418 F.2d at 782." Id. Drawing an analogy to Baker v. Carr, 369 U.S. 186, 217, 82 S.Ct. 691, 710, 7 L.Ed.2d 663 (1962). Payton additionally inquires "whether the activity is one traditionally or constitutionally exercised by a coordinate branch of government or one fraught with political or policy overtones such as the feasibility or practicality of a program, Dalehite v. United States, 346 U.S. at 34, 73 S.Ct. at 967,. . . or prosecutorial discretion, Smith v. United States, 375 F.2d at 248, and whether this injurious activity is in an area of potential government embarrassment such as foreign affairs." Id., at 144-145 (footnote omitted). Further, Payton urges "a careful assessment of the actual burden, in both the long and short run, on governmental activities and the alternatives available. . . " Id, at 145 (footnote omitted).

Finally, Payton looks to the amenability of the subject-matter of the suit to the judicial process:

"The Court should consider, whether the vehicle of a tort suit provides the relevant standard of care, be it professional or reasonableness, for the evaluation of the governmental decision. Hendry v. United States, 418 F.2d at 783. Similarly, the Court should determine whether the factors for decision are primarily of such political, social or economic nature as to be beyond the Court's experience gained even in civil rights and antitrust litigation. . . . On this point complexity alone is not dispositive, but rather the Court should assess the nature of the complications and their amenability to the judicial process of evidential offering, evaluation and determination. See Griffin v. United States, 500 F.2d at 1064." Id. at 145 (citation omitted).

"Judicial intervention in such decisionmaking through the vehicle of private tort suits would involve the courts in poli-

tical, economic, and social decisions in apparent violation of the separation of powers principle that we perceive the discretionary function exception statutorily to embody. Further, precisely because these decisions would require consideration of factors that are primarily political, social, and economic in nature, they, unlike the professional evaluative judgments challenged in Griffin, would not be the type of determinations that the courts are "fully capable of scrutinizing. . . by the usual standards applied to cases of professional negligence." 500 F.2d at 1066-67; Blessing v. United States, 447 F. Supp. 1160, 1180-1183 (E.D.Pa. 1978) (footnotes omitted).

Most important to the litigation now proceeding before this Court is the fact that the United States Court of Appeals for the Tenth Circuit has expressly approved of the analytical approach applied in Griffin and similar cases. First National Bank in Albuquerque v. United States, 552 F.2d 370, 375 (10th Cir. 1977). In Jackson v. Kelly, 557 F.2d 735 (10th Cir. 1977), the Court through Chief Judge Lewis wrote:

"Generally speaking, a duty is discretionary if it involves judgment, planning, or policy decisions. It is not discretionary if it involves enforcement or administration of a mandatory duty at the operational level, even if professional expert evaluation is required. . . The key is whether the duty is mandatory or whether the act complained of involved policy-making or judgment. . . " Id., 557 F.2d at 737-738 (citations omitted). The Court of Appeals in Wright v. United States, 568 F.2d 153 (10th Cir. 1977) reaffirmed the "policy" approach to § 2680(a), commenting that "The 'discretionary function' exemption to tort liability is auxiliary to the government's ability to formulate and implement policy." Id., 568 F.2d at 158. See also Smith v. United States, 546 F.2d 872 (10th Cir. 1976). Most recently, the Tenth Circuit Court of Appeals held the Government to be immune from liability for damages resulting from an alleged lack of important detail in an aeronautical chart produced in compliance with

federal regulations, which plaintiffs claimed resulted in the crash of their aircraft. The Court found the promulgation of the governing regulations to be sufficiently imbued with public policy concerns to be "discretionary" within the meaning of 28 U.S.C. § 2680(a).

Certainly a number of the decisions and judgments that went into the conduct of the atomic tests represented the exercise of discretion at the highest levels of government. It is fundamental that for those decisions, the United States is immune from tort liability.

But, one must understand that the words "discretionary function" as used in the Tort Claims Act, are really the correlative, the other side of the coin, of the exercise of executive power. The discretionary function exception merely reaffirms that courts should not interfere with executive decision making at the highest levels. Whether or not testing should be performed at all is obviously insulated from judicial interference. But, one must also recognize that discretion functioning at a presidential level, at a cabinet level or at an Atomic Energy Commission level is not the same thing at all as the exercise of judgment at a regional level, or at a site level, by a G.S. 16 manager, a scientist, an engineer, a public affairs information officer, and auxiliary personnel.

While the word "discretion" may be spelled the same and sound the same, looking beyond the word, the function performed at each level of activity is a discretely different function.

Our job, of course, is to look beyond the words to the context in which a particular person may have been hurt and to determine if in that context the cost of that hurt to that person should be borne alone by that person or shared by all for whose benefit the hurt may have been inflicted. Proceeding down the descending ladder of abstraction, from the

general policy formulated on the highest level to the concrete implementation of that policy, one must understand that the case here is not footed on the fact that high level policy decisions were made—but is footed on the alleged, inappropriate manner in which such policy decisions were carried out. The distinction cries out.

As a conceptual device one may visualize the process as an inverted pyramid. The broad policy decision is at the top. As one descends, a multitude of judgments are made and functions and procedures performed in implementing the policy decision. Each such decision is quite obviously not the policy decision. Each is made at a different functional level and each is made in a different context and at a different time.

In short, when we speak of discretion we must focus on the specific level in the descending pyramid of decision making to see if, at that point, in that distinctive context of time and place and people, government actions are of such a nature that persons who are hurt through government actions at that level should in good conscience be made whole.

To re-iterate, discretion at one level may well be insulated and indeed should be. Judgment and related activity at a differing level may not be insulated and indeed should not be.

527 F. Supp. at 479-485 (footnotes omitted).

Let us look beyond the words and see what the United States did or did not do about which plaintiffs complain. Then let us see if such acts were so imbued with considerations of public policy and governance as to be immunized from the reach of the Federal Tort Claims Act.

First, there is no complaint that testing took place. To test or not to test is a policy decision. See e.g., "Review of Establishment of Continental Test Site," AEC Santa Fe Operations Office (Sept. 1953), PX-52/DX-1A. Obviously the United States has not consented to be sued for what Harry Truman or Dwight Eisenhower or the Atomic Energy Commission or the Congress determined as

a matter of policy and governance ought to be done. E.g. DX-127, 120-21, 146, 147, 177, 804, 171, 203, 330, 331, 333, 406 (memoranda concerning Presidential approval of the Buster-Jangle, Tumbler-Snapper, Upshot-Knothole, Teapot, and Plumbbob series of tests). This action does not challenge the decision to test.

The United States seems to argue that because a choice has been made, a discretionary choice at the highest levels of government, that all subsequent operational choices and actions executing the original policy choice are to be regarded as identical with the original policy choice, and insulated as the original choice is insulated from the reach of the Tort Claims Act.

The United States misperceives the intent of the act. For example, we choose the objective: Rome. We choose the road: the Appian Way. Discretionary choices both. We make such choices as a matter of power and as a matter of right.

The manner in which we drive from our location to Rome, carelessly or carefully, is also a matter of choice. But, it is not a matter of discretion as used in the Tort Claims Act. It is not a matter of discretion because such a choice is subject to a standard, a limitation. It is subject to a limitation imposed by a civilized society as to appropriate conduct.

It is not a matter of discretion because while we have a power to choose, we have no right to breach the standard and without responsibility choose to drive carelessly. If we do, we are answerable for exercising power without right.

In 1951, in response to international pressures, the United States chose the objective—to try to stabilize the restless balance of world power. It chose the road—open air atomic testing.

Discretionary choices both. Both choices were made as a matter of power and as a matter of right.

The manner in which the tests were conducted, carefully or carelessly, was also a matter of choice but was not a matter of discretion because such operational conduct was subject to a stan-

dard, a limitation. That limiting standard of conduct, due care, reasonable care under the circumstances, is called a duty. The person to whom a duty is owed is said to have a right.

At the operational level employees of the United States had a duty to prepare and conduct tests carefully with full regard for public safety. The citizen adjacent to the testing site had a right to have that duty fulfilled. See part VIII, infra.

Much like the driver on the road to Rome, an operational employee had the power to conduct such tests carelessly, but he had a duty to do otherwise. The duty limits choice and thus belies discretion or its exercise.

When a decisionmaker with genuine power and right to make discretionary choices makes such a choice, an operational person down the decision-making and administrative ladder—charged by the decisionmaker with the responsibility for executing but not making such choice—is not in a position to overrule or to nullify the original discretionary choice, either through choices of his own or through negligent operational actions of his own. That original discretionary choice has been made. There are no rightful operational vetoes of appropriate discretionary choices. That kind of discretion does not exist. This is simply another reason why the position of the United States lacks persuasion. See Part VIII(E), infra.

The United States misreads 28 U.S.C.A. § 2680(a) and does so in two ways. It misreads the second clause as explained in the analysis set forth above. It misreads the first clause by not reading it at all.

The paragraph has two clauses with two separate ideas separated by the word "or."

The first clause of § 2680(a) concerns the execution of a statute or a regulation. When an employee executes a statute or regulation with "due care" the government has not consented to be sued and this court is without jurisdiction.

That clause says in a negative fashion what 28 U.S.C. § 1346(b) and 28 U.S.C. § 2674 say in a positive fashion, namely that the government is liable "for personal injury or death caused by the negligent or wrongful act or omission of any employee of the government when acting within the scope of his office or employment. . . in the same manner and to the same extent as a private individual under like circumstances. . . "

The jurisdictional standard is equated with the negligence standard, namely action by an employee which falls below the standard of "due care" in executing a statute or regulation.

The acts complained of here are not discretionary within the meaning of the exception. Implicit in the idea of discretion as used in the Tort Claims Act is the idea of conscious consideration—the exercise of deliberate choice of a particular course of action to achieve a particular governmental objective.

Distilled to its essence plaintiffs do not complain of what defendant did do. They complain of what defendant didn't do—namely that it did not adequately warn, did not adequately and contemporaneously measure, and did not adequately educate the population at hazard in simple and inexpensive preventative and mitigating measures.

At no time has the defendant ever asserted that as a matter of conscious choice it deliberately adopted a policy of not warning, not measuring and not educating the populace at hazard.

The United States simply did not make such a conscious choice. At the highest levels of government, in the Congress, in the Executive Office, and in the Atomic Energy Commission, public safety was a stated government objective. There was no official policy of indifference to safety.

This court's review of the excerpted minutes of meetings of the Atomic Energy Commission submitted by the parties discloses a fairly clear delineation of duty, discretion and responsibility, i.e.,

of policy-making authority, between the Commission and personnel at the Nevada Test Site. Expressing continuing concern for public and worker safety from the commencement of the continental test program. See e.g., Minutes of the AEC Meeting No. 755 (Sept. 23, 1952) DX-696 at 504, the Commission established criteria concerning exposure levels from radioactive fallout for workers and the off-site public—a policy decision—which were to be implemented at the operational level by test site personnel. The Commission also dealt with questions of timing, frequency and size[87] of tests in general fashion, leaving the Santa Fe Operations Office and the test site organization to work out specific details. See e.g. Minutes of AEC Meeting No. 763 (Oct. 7, 1952), PX-414; Minutes of AEC Meeting No. 862 (May 13, 1953), DX-167; Minutes of AEC Meeting No. 1063 (March 1, 1955), DX-329 (concerning fallout from proposed TURK shot, "the Commissioners indicated that General Fields should be governed by the approved radiological safety criteria for the test operation. . . "); Minutes of AEC Meeting No. 1060 (Feb. 11, 1955), DX-40, 327, 702 (the Commission noted "that operational means for giving effect to the [radiological safety] criteria in Appendix "B" [of AEC 141/27] will be developed by the Test Manager and the Division of Military Application with the technical guidance of the Division of Biology and Medicine;. . . "); Minutes of AEC Meeting No. 1246 (Nov. 14, 1956), DX-704, at 699. Perceptions by military personnel involved with testing were that the Atomic Energy Commission allowed "the Test Organization complete freedom in directing its operations, subject to using 'all the means at its disposal to decrease fallout in communities surrounding the Nevada Proving Grounds.' " Letter, Lt. Col. R. Campbell to Cpt. W. Guthrie, USN, of July 27, 1953, PX-1015 at 1-2 (emphasis added). Once policy has been made in the form of radiological safety criteria, the "operational procedures" necessary to meet those criteria, the Commission declared, "shall be the responsibility of the Test Manager, as directed by the Division of Military Application. . . " Atomic Energy Comm'n. "Radiological Safety Criteria and Procedures for Protecting the Public During Weapons Testing at the Nevada Test Site, at 1 (Feb. 1955), PX-28/DX-689, id., (Feb. 1957), Px-27.

Where off-site radiological safety was concerned, the Atomic Energy Commission, not the Test Organization, determined policy and set criteria; where operational enforcement of those policy judgments were concerned, responsibility clearly fell upon the Test Organization. See e.g., DX-800, 128, 148, 284 (AEC documents designating a Test Manager responsible for operational activities, including safety.)

At the operational level, where the stated effort at public safety was to be achieved on a day-to-day basis, actions taken were negligently insufficient—not as a matter of discretion at all—a matter of deliberate choice making—but as a matter of negligently failing to warn, to measure and to inform, at a level sufficient to meet the stated goals of the Congress, the Executive Branch and the Atomic Energy Commission.

That is first clause responsibility under section (a) of the Tort Claims Act and that is first clause negligence for which the United States has agreed to answer.

That is not second clause discretion in action at all.

Such activities could be discretionary, in some circumstances, but are not in this instance.

A hypothetical will illustrate my point.

Let me caution that this is a hypothetical. The United States does not assert that it happened. Indeed it denies that it happened. I am convinced that it did not happen. It illustrates my point that the acts complained of here are non-discretionary in nature.

Suppose a high level decision maker says, "International pressures make openair atomic testing highly necessary. Time is of the essence. We cannot tell our own people. We just need to do it and do it as fast as we can. We know as a result of such testing some people are going to get hurt. We can't tell them they are going to get hurt. We can't even warn them what to do to minimize or prevent the hurt. In order to preserve our way of life some people

unknown to them and unknown to us are going to give their all for the good of all."

Policy decision? Yes. Tort Claims Act exception.

Assuming appropriate power in the decisionmaker—a court, this court, would lack power to do anything at all about such a policy decision. Under that hypothetical, Congress, as a matter of conscience and not as a matter of legal duty would, it seems to me, recognize the equities and make redress as best it could.

That is not this case. Nowhere in the 7,000 pages of record was that kind of a decision made, eyes open, as a high-level or low-level policy decision. Nowhere were there to be human guinea pigs as a matter of policy. That is simply not here.

Indeed the opposite appears to be the case. The AEC Committee to Study the Neveda Proving Grounds stated in a heretofore-secret document dated September 23, 1953, concerning the public relations of Continental Tests:

> It is suggested that the following operational actions would advance public safety and public relations in the fallout field:
>
> (1) A definition and interpretation of the full nature of the radiation hazard (or exposure) which the public in various geographic areas are asked to accept, or may experience in any degree of emergency.
>
> (2) Detailed advance planning of action to be taken to reduce, avoid, or correct exposure to fallout in all situations which may be anticipated.
>
> (3) Centralizing off-Site radiation monitoring during operations under a competent official who will have continuity of assignment, with provision of personnel and other resources to fully perform field monitoring, emergency action, and the investigation and settlement of claims. It is noted that the individual should be qualified to conduct a continuing public indoctrination program throughout the region.

(4) The most extensive possible program of education in the facts of hazard, the meaning of exposure, controls and emergency actions, etc., through all possible channels, including on-Site participants and observers, AEC and related personnel, opinion leaders such as doctors, health officials, news media, etc., etc.

(5) Expansion of the shot-time warning procedure to include timely advice to news media and to affected private enterprise. Issuance of advance warnings within the NPG region at the earliest moment when it is indicated that the affected publics have been sufficiently educated.

(6) Prompt public reports of exposure experienced, within the MPG region and nationally, with interpretations. It is believed particularly advisable for the AEC and the test organization to initiate such reports to persons affected, and most particularly when exposure approaches "significant" levels.

(7) To press for authorization permitting prompt local investigation, evaluation, and settlement of radiation claims.

"The Public Relations of Continental Tests," Attachment I to Abstract of Committee Report (Sept. 23, 1953) PX-62/DX-11, at 16-17; see also Abstract of Committee Report, PX-51/DX-1, at 59.

It is interesting to note the Committee's characterization of such activities as "operational actions" in contrast to how the United States has characterized them in this litigation.

The full record fortifies my original determination.

If a truck driver was hauling plutonium from Los Alamos, New Mexico to the Nevada Test Site and his superiors told him to be careful, but he was careless and someone got hurt, it would be absurd to suggest the United States was insulated from suit because his acts were "discretionary," i.e., involving judgment.[88] Even law enforcement officers, who exercise considerable "police discretion" in the handling of search and arrest activities, are not insulated from liability as a matter of law; the discretionary function exception protects those governmental activities "involving

policy formulations as distinguished from the day-to-day activities of persons not engaged in determining the general nature of the Government's business." Downs v. United States, 522 F.2d 990, 1002 (6th Cir. 1975); see Note, 45 Cincinnati L. Rev. 157 (1976). It is the nature of the specific decision, not the fact that some decision or choice was made, that is important. See Comment, "The Discretionary Function Exception: Is It a Bar to Federal Jurisdiction?" 1983 Utah L. Rev. 117, 124-26, 136-37.

The acts and omissions complained of here are comparable.

In the first Allen opinion, this court observed that "one must understand that the case here is not footed on the fact that high level policy decisions were made—but is footed on the allegedly inappropriate manner in which such policy distinctions were carried out. The distinction cries out," even more loudly now than before.

For the reasons set forth in the first Allen opinion as amplified here, the discretionary function exception for the operational activities complained of is simply unavailable.

Jurisdiction is proper. Defendant's Motion to Dismiss based on the discretionary exception is denied.[89]

VI. STATUTE OF LIMITATIONS

Section 2401 of Title 28, United States Code reads in pertinent part as follows:

> (b) A tort claim against the United States shall be forever barred unless it is presented in writing to the appropriate Federal agency within two years after such claim accrues or unless action is begun within six months after the date of mailing, by certified or registered mail, of notice of final denial of the claim by the agency to which it was presented. [Emphasis added.]

In Allen v. United States, 527 F. Supp. 476, 489-91 (D.Utah 1981), this court dealt with the applicability of 28 U.S.C. § 2401(b)

to the plaintiffs in this action on a preliminary basis. At that time, this court stated:

> The appropriate inquiry as to each plaintiff would seem to be whether more than two years prior to the filing of the plaintiff's claim the information known to, or reasonably imputed to the plaintiff was sufficient to put the plaintiff on notice that (1) he or she had been injured, and (2) that exposure to radioactive products of the Government's Nevada testing program is the cause of that injury to the reasonable exclusion of alternative causes. Where the information possessed by a plaintiff was sufficient to satisfy this dual inquiry, his or her claim is barred by 28 U.S.C. § 2401(b); where it was insufficient, the plaintiff may now proceed.

Id. at 490 (emphasis in original). As pointed out in the first Allen opinion, this two-year statute of limitations "commences to run from the point at which the plaintiff's knowledge of his injury and its cause is sufficient to fairly justify placing the burden of inquiry upon him as to its legal consequences." Id.

The standards just expressed were derived from prior case law, such as United States v. Kubrick, 444 U.S. 111 (1979), a Federal Tort Claims Act suit involving medical malpractice. In Kubrick, the United States Supreme Court held that a cause of action "accrues" under 28 U.S.C. § 2401(b) when the plaintiff knows of the facts of his injury and its cause:

> That he has been injured in fact may be unknown or unknowable until the injury manifests itself; and the facts about causation may be in the control of the putative defendant, unavailable to the plaintiff or at least very difficult to obtain. The prospect is not so bleak for a plaintiff in possession of the critical facts that he has been hurt and who has inflicted the injury. He is no longer at the mercy of the latter. There are others who can tell him if he has been wronged, and he need only ask.

444 U.S. at 122 (emphasis added). As explained in the first Allen opinion, the Kubrick standard readily lends itself to a case such as

this, in which the injury does not manifest itself until years—sometimes decades—later and in which the critical facts concerning injury or causation are difficult if not impossible to early ascertain. 527 F. Supp. at 489-91. Construing the statute in this fashion avoids the impossible burden that would be placed on a plaintiff who would otherwise be expected to commence a lawsuit years before he knew he had an injury, knew the source of the injury and thus knew he had a cause of action. In such cases, the underlying policy of the statute of limitations, discouraging litigation of "stale" claims, does not arise. The claim is not stale. It merely took time to accrue. Genuine concern about lost evidence, fading memories and the passage of time are subordinated to a greater concern that legal wrongs be remedied at the first practical opportunity.

In this case, the statute of limitations defense raises special problems for the defendant United States. It seems to force the United States to argue conflicting positions. On the one hand, the Government argues that the existing scientific information about fallout and its effects on the human body falls far short of establishing a causal relationship between its conduct in open air atomic testing and the plaintiffs' injuries; on the other hand, the Government asserts that each plaintiff knew or should have known with requisite certainty that fallout was the cause of his illness at least by 1977, if not before. If both arguments are given equal force, the plaintiffs are charged with long-standing knowledge of that which the Government says even now is unknowable.

The considerable time spent reviewing the record and exhibits relating to the causal relationship between cancer and ionizing radiation has awakened this court's concern as to whether any layman could reasonably be said to have the requisite knowledge of the causal relationships—particularly during the years prior to the commencement of this action. The cause-in-fact issues in this lawsuit are extraordinary and complex. See Part IX, infra. Cancer induction by ionizing radiation is a far more technical problem than the simple A-collides-with-B chain of causation found in most tort actions. Historically expert opinion on the issue of causation of many biological consequences has been deeply divided. There is no sign of consensus insight.

Certainly each of the plaintiffs knew in a general way about the ongoing test program at the Nevada Test Site. Each plaintiff was aware to a greater or lesser degree of something called radiation and radioactivity. Several of the plaintiffs were aware of a possible link between exposure to radiation and illness. Beyond these general impressions, however, hard information readily available to the plaintiffs in each of the 24 cases during those years was minimal.

A careful review of the collection of newspaper clippings, magazine articles, official pamphlets and documentary film materials concerning testing in Nevada leaves the reader with a notion of some level of risk associated with nuclear fallout.[90] When discussed in the contemporaneous news coverage, serious fallout risk is associated much more with the detonation of hydrogen bombs in the Pacific (never at Nevada), incidents such as the serious contamination of the Japanese fishing boat Lucky Dragon, and because of the stunning power and deadliness of the then mononuclear weapon. Furthermore, any notion of serious hazard is softened by the ambivalence of much of the material. News photos of scientists dining on experimental meals laced with strontium-90, see "A Searching Inquiry into Nuclear Perils," 42 Life 24, 26 (June 10, 1957), DX-1207, and repeated AEC reassurances of safety, see e.g., U. S. News & World Report, June 28, 1957, at 79 et seq., DX-1208, lessen any impression of serious potential risk. Concerns expressed by offsite residents are noted, but often juxtaposed with a reassuring agency denial. E.g., U. S. News & World Report, Nov. 20, 1961, at 48, DX-1230.

Notables such as Dr. Lauriston S. Taylor, Chief of the Radiation Physics Division, National Bureau of Standards, in 1961 sought to "give a little perspective" to the fallout problem by reporting that the average cumulative exposure due to fallout by 1960 equalled that experienced by watching television. See DX-1230, supra at 50. In 1966, the Surgeon General of the United States, William Stewart, noted a recent increase in thyroid gland inflammation among children in Utah and elsewhere in the country, but quickly added, "there is no proof that radiation, from fallout or other sources, has anything to do with it." Time, March 25, 1966, DX-1233.

There were voices counseling much greater caution in dealing with fallout, such as a book by Dr. Linus Pauling which appeared in 1958 entitled No More War!. Given far wider circulation, however, was an article by Dr. Edward Teller, "father of the hydrogen bomb" and Albert Latter in the February 10, 1958 Life magazine entitled "The Compelling Need for Nuclear Tests." Teller and Latter confidently assure the public that "worldwide fallout is as dangerous to human health as being one ounce overweight, or smoking one cigarette every two months." Id. Residents of St. George and other nearby communities could on one night attend a screening of a government film advising them in that the best minds in the country were at work in the Nevada desert protecting them from any danger, and attend the Saturday matinee showing of The Amazing Collosal Man—about a soldier directly exposed to explosion of a "plutonium bomb" in the same desert who quickly grows into a giant, or the classic Godzilla, a prehistoric reptile who left a trail of "hot" footprints rich in strontium-90. To say the least, the world of radiation was exotically esoteric, a subject best left to experts. One St. George resident was reported to have said

> The tests don't worry me. I think that the guys who are doing it are competent. If they weren't, they wouldn't be doing it.

U. S. News & World Report, June 28, 1957, at 81, DX-1208.

At what point does the 2-year limitations clock start to run? At what point are critical facts in possession of plaintiff? The testimony and documents in the record have led this court to draw a distinction between the level of knowledge required and the less-sure level of suspicion. Knowledge, either actual or reasonably imputed knowledge, which meets the criteria previously set forth starts the clock; mere suspicion does not. There is a crucial difference between the two.

Knowledge is defined in Webster's New World Dictionary as "the act, fact, or state of knowing;. . . "id. at 781 (2d Coll. ed. 1980). What does it mean to "know" something? Webster's provides some guidance:

know (nō) *vt.* knew, known, know'ing [ME. *knowen* < OE. *cnāwan*, akin to OHG. *-cnāhan* < IE. base **ĝen-*, **ĝno-*, to know, apprehend, whence L. *gnoscere*, to know, Gr. *gignōskein:* cf. CAN[1], KEN, GNOMON, GNOSTIC] **1.** to have a clear perception or understanding of; be sure of or well informed about [to *know* the facts] **2.** to be aware or cognizant of; have perceived or learned [to *know* that one is loved] **3.** to have a firm mental grasp of; have securely in the memory [to *know* the multiplication tables] **4.** to be acquainted or familiar with **5.** to have understanding of or skill in as a result of study or experience [to *know* music] **6.** to recognize [I'd *know* that face anywhere] **7.** to recognize as distinct; distinguish [to *know* right from wrong]

Understanding, well informed are helpful words.

knowl·edge (näl'ij) n. [ME. *knoweleche*, acknowledgment, confession < Late OE. *cnawlæc* < *cnawan* (see KNOW) + element of unc. orig.] **1.** the act, fact, or state of knowing; specif., *a*) acquaintance or familiarity (with a fact, place, etc.) *b*) awareness *c*) understanding **2.** acquaintance with facts; range of information, awareness, or understanding **3.** all that has been perceived or grasped by the mind; learning; enlightenment **4.** the body of facts, principles, etc. accumulated by mankind **5.** [Archaic] sexual intercourse—*SYN.* see INFORMATION—to (the best of) one's knowledge as far as one knows; within the range of one's information.

Information is a key word.

Id. The American Heritage Dictionary offers clarification:

knowl·edge (näl'ij) *n.* **1.** The state or fact of knowing. **2.** Familiarity, awareness, or understanding gained through experience or study. **3.** That which is known; the sum or range of what has been perceived, discovered, or inferred. **4.** Learning; erudition: *men of knowledge.* **5.** Specific information about something. **6.** *Obsolete.* Sexual intercourse; copulation. Now used only in the phrase *carnal knowledge.* [Middle English *knowlege*, *know(e)lech*, from *cnawlechen*,

know(e)lechen, to confess, recognize, Old English *cnāwlæcan* (unattested), from *cnāwan*, to KNOW.]

Synonyms: knowledge, information, learning, erudition, lore, scholarship, wisdom, enlightenment. These nouns refer to cognitive or intellective mental components acquired and retained through study and experience. *Knowledge* includes both empirical material and that derived by inference or interpretation. *Information* is usually construed as narrower in scope and implies a random collection of material rather than orderly synthesis. *Learning* usually refers to what is gained by schooling and study, and *erudition* adds to this the idea of profound knowledge often in a specialized area. *Lore* is knowledge gained by tradition or intuition rather than formally. The remaining terms refer to qualities possessed by persons rather than directly to what is stored in their minds. *Scholarship* is the distinctive mark of one who has mastered some area of learning, as reflected in the quality of his work, especially with respect to scope, thoroughness, and care. *Wisdom* involves sound judgment and the ability to apply what has been acquired mentally to the conduct of one's affairs. *Enlightenment* is the state of possessing knowledge and truth.

Id. at 725 (1981 ed.). Black's Law Dictionary sheds additional light based directly upon prior case law:

Knowledge. Acquaintance with fact or truth. People v. Henry, 23 Cal.App.2d 155, 72 P.2d 915, 921.

It has also been defined as act or state of knowing or understanding, Witters v. U.S., 70 App.D.C. 316, 106 F.2d 837, 840; People v. Henry, 23 Cal.App.2d 155, 72 P.2d 915, 921; actual knowledge, notice or information, New York Underwriters Ins. Co. v. Central Union Bank of South Carolina, C.C.A.S.C., 65 F.2d 738, 739; Howard v. Whittaker, 250 Ky. 836, 64 S.W.2d 173; Cooper v. Independent Transfer & Storage Co., 52 Idaho 747, 19 P.2d 1057, 1058; assurance of fact or proposition founded on perception by senses, or intuition; clear perception of that which exists, or of truth,

fact or duty; firm belief, Witters v. U.S., 70 App.D.C. 316, 106 F.2d 837, 840; guilty knowledge, Goldsworthy v. Anderson, 92 Colo. 446, 21 P.2d 718; information of fact, Green v. Stewart, 106 Cal.App. 518, 289 P. 940, 944; means of mental impression, Howard v. Whittaker, 250 Ky. 836, 64 S.W.2d 173; miscellaneous information and circumstances which engender belief to moral certainty or induce state of mind that one considers that he knows; Wise v. Curdes, 219 Ind. 606, 40 N.E.2d 122, 126; notice or knowledge sufficient to excite attention and put person on guard and call for inquiry, Iberville Land Co. v. Amerada Petroleum Corporation, C.C.A.La., 141 F.2d 384, 389; Hayward Lumber & Investment Co. v. Orondo Mines, 34 Cal.App.2d 697, 94 P.2d 380, 382, 383; Reynolds v. Moseley, C.C.A.ARk., 32 F.2d 979, 981; personal cognizance or knowledge or means of knowledge, The Chickie, D.C.Pa., 54 F.Supp. 19, 20; Taylor v. Moore, 87 Utah 493, 51 P.2d 222, 229; In re Eastern Trnsp. Co., D.C.Md., 37 F.2d 355, 363; state of being or having become aware of fact or truth; Howard v. Whittaker, 250 Ky. 836, 64 S.W.2d 173.

When knowledge of the existence of a particular fact is an element of an offense, such knowledge is established if a person is aware of a high probability of its existence, unless he actually believes that it does not exist. Model Penal Code, § 2.202.

Knowledge consists in the perception of the truth of affirmative or negative propositions, while "belief" admits of all degrees, from the slightest suspicion to the fullest assurance. The difference between them is ordinarily merely in the degree, to be judged of by the court, when addressed to the court; by the jury, when addressed to the jury.

Id. at 784 (5th ed. 1979). "Knowledge" speaks to the direct interaction between the mind and that which exists—facts, information, truth, understanding.

Suspicion, on the other hand, speaks to the formation of subjective impression or belief:

sus·pect (sə spekt′; *for adj. usually, & for n. always*, sus′pekt) *vt.* [LME. *suspecten* < L. *suspectus*, pp. of *suspicere*, to look under, look up to, admire, also to mistrust < *sus-* (see SUB-), under + *spicere*, to look (see SPY)] **1.** to believe (someone) to be guilty of something specified, on little or no evidence **2.** to believe to be bad, wrong, harmful, questionable, etc.; distrust **3.** to think it probable or likely; guess; surmise; suppose—*vi.* to be suspicious; have suspicion—*adj.* viewed with suspicion; suspected—*n.* a person who is suspected, esp. one suspected of a crime, etc.

* * * *

sus·pi·cion (sə spish′ n) *n.* [ME. *suspecion* < Anglo-Fr. *suspecioun* < OFr. *sospeçon* < LL. *suspectio*, orig., a looking up to, esteeming, later with sense and sp. of L. *suspicio*, suspicion < L. *suspecius*, pp. of *suspicere*, to look up at, admire, look secretly at, mistrust, suspect] **1.** the act or an instance of suspecting guilt, a wrong, harmfulness, etc. with little or no supporting evidence **2.** the feeling or state of mind of a person who suspects **3.** a very small amount or degree; suggestion; inkling; trace—*vt.* [Dial.] to suspect—above suspicion not to be suspected; honorable—on suspicion on the basis of suspicion; because suspected—under suspicion suspected.

Webster's New World Dictionary, supra, at 1434, 1435;

sus·pect (sə-spĕkt′) *v.* *-pected*, *-pecting*, *-pects*. —*tr.* **1.** To surmise to be true or probable; imagine. **2.** To have doubt about or distrust of. **3.** To think (a person) guilty without proof. —*intr.* To have suspicion. —*n.* (sŭs′pĕkt′). One who is suspected, especially of committing a crime. —adj. (sŭs′pĕkt′). Open to or viewed with suspicion. [Latin *suspectare*, intensive of *suspicere* (past participle *suspectus*), to look up at, watch : *sub-*, up from under + *specere*, to look at (see spek- in Appendix*).]

* * * *

sus·pi·cion (sə-spĭsh′ n) *n.* **1.** The act of suspecting the ex-

> sistence of something, especially of something wrong, without sufficient evidence or proof. **2.** A minute amount; hint; trace. —See Synonyms at uncertainty. —*tr.v.* suspicioned, -cioning, -cions. *Nonstandard.* To suspect. [Middle English *suspicio(u)n*, from Old French *suspicion*, from Latin *suspiciō*, from Latin *suspicere* (past participle suspectus), to look at secretly, sus-PECT.] —**sus·pi'cion·al** *adj.*

The American Heritage Dictionary, supra, at 1296; turning again to Black's Law Dictionary, suspicion is defined as

> The act of suspecting, or the state of being suspected; imagination, generally of something ill; distrust; mistrust; doubt. The apprehension of something without proof or upon slight evidence. Suspicion implies a belief or opinion based upon facts or circumstances which do not amount to proof.

Id. at 1298 (5th ed. 1979). Knowledge and suspicion are distinguished from each other by the degree of interplay between the mind and the facts. And the facts themselves? The dictionaries speak of the thing that has actually happened or that is really true. Webster's New World Dictionary, supra at 501, or as something "known with certainty. . . something that has been objectively verified. . . having real, demonstrable existence." The American Heritage Dictionary, supra, at 469. "Knowledge" of "fact" carries as unmistakable sense of certainty, of objective proof or at least that the fact "known" is more likely than not. That which is known can readily be shared with others often by pointing them to the fact claimed known. This is the basis of our entire law of evidence, and of "fact-finding" by courts. The court is told and is shown. See e.g., 1 Wigmore on Evidence §§ 1, 2 (rev. ed. Tillers 1983). Indeed, a fundamental premise of scientific knowledge of fact or principle is the repeatability of the observation. One is shown. Experimental process and product which cannot be duplicated are viewed with great skepticism.

"Suspicion" is inextricably tied to the notion of uncertainty, to a scarcity of "facts" by which one could "know" rather than merely imagine or suspect. One suspects that which he cannot prove, a more intuitive than demonstrative exercise.

Particularly in a case as complex as this one, it just seems to make common sense that the running of the statute of limitations begins when knowledge of injury and reasonable knowledge of its cause are attained. Suspicion will not suffice, no matter how well-founded early suspicions may appear in retrospect. A plaintiff with the requisite quantum of knowledge (or reason to have such knowledge) has received—seized, grasped, understood—facts. Knowledge requires at least a modest factual basis, one to which the perceptive minds of others may be pointed.

Using suspicion alone as the basis for starting the clock may exhaust a plaintiff's time to pursue relief well before he can assemble provable "facts" in support of his claim. The statutes of repose are designed to insulate the judicial process against actions which, once crystallized, have then grown old and stale through the passage of time. They are not intended to stimulate the filing of actions arising from injuries or causes that have not been rationally identified.

Under Utah law, "the statute of limitations is tolled until the plaintiff knew or with due diligence should have known of his cause of action in 'exceptional circumstances or causes of action where the application of the general rule would be irrational or unjust.'" Vest v. Bossard, 700 F.2d 600, 608 (10th Cir. 1983), quoting Myers v. McDonald, 635 P.2d 84, 86 (Utah 1981). In Vest v. Bossard, the U.S. Court of Appeals for the Tenth Circuit held that the "exceptional circumstances" tolling concept "does not apply when the plaintiff is aware that he has been harmed unless there are 'exceptional circumstances' or he has an 'exceptional cause of action' that would cause him not to investigate the cause of his injury or that would hinder the investigation," 700 F.2d at 608 (opinion of McKay, J.) (emphasis added); see id. at 601-04 (opinion of Doyle, J.). Among the conditions that the court of appeals identified as satisfying this criterion were concealment of the existence of the cause of action by a putative defendant, and cases such as medical malpractice actions, when there is a "great disparity in knowledge between the providers and the recipients of health care"—that is, specialized knowledge of cause and effect beyond "the untutored understanding of the average layman."

Id. at 609 n. 3 (opinion of McKay, J.); accord, id. at 601-04 (opinion of Doyle, J.).

The analysis offered in the Vest opinions is relevant to this case: the court of appeals held that a finding of reasonable suspicion on the part of the plaintiff was insufficient to initiate the running of the statutory period. Actual knowledge of facts material to his federal cause of action was required. In this action, many of the plaintiffs have held varying degrees of suspicion concerning the nexus between fallout and cancer incidence in the downwind Utah, Nevada and Arizona communities. Until very recently, hard data and information—"facts"—corroborating those suspicions have not been made available to the plaintiffs or their neighbors in these small, outlying rural communities. Much of the scientific data concerning dosimetry or cancer incidence that is relevant to this action has been developed since the filing of this lawsuit in 1979. Several major studies are in process even now, with results to be reported months, or even years hence.

Of the plaintiff in Vest, Judge Doyle observed that "[f]or him to file a lawsuit that he could not prove up would have been folly and certainly the law should not encourage that kind of activity. . . ." Id. at 604. The same may be said of the 24 claims tried here when the state of knowledge held by plaintiffs prior to 1977 is evaluated. While the Vest opinions did not construe the statute of limitations under the Federal Tort Claims Act, their reasoning seems at least as strong in this context.

Aside from policy reasons which are traditionally used to justify statutes of limitation, there are three elements implicit in the statute which must be specifically examined with care.

The first is the specific information which is said to be known or which should be known by each plaintiff.

The second is the time when it is said to be known by each plaintiff.

The third is whether the quantum of information possessed in fact by plaintiff at the time he is said by the United States "to

know" such information is sufficient to show injury and who caused the injury.

What is it that each plaintiff is charged with knowing more than two years before his claim was administratively filed?

As a prelude it should be noted that a principal ground for complaint is that the United States failed to tell plaintiffs what it knew about the long range hazards to plaintiffs of radiation fall out and how to minimize them and to do so from its position of superior knowledge. It now appears to be the position of the United States that each of these lay plaintiffs should have known what the United States then knew but did not tell them.

That assertion sounds a discordant note. Knowledge sought now to be imputed to plaintiffs could have simply been imparted to plaintiffs by defendant at the time of the tests.

At best some of these plaintiffs could be said to have information of a very general nature, essentially a suspicion, that there may be some connection between radiation and cancer. That suspicion in the minds of laymen of the long-term biological consequences of exposure to atomic fallout could not ripen into knowledge absent divination of the complexities set forth in esoteric texts,[91] and the penetration of classified documents within the exclusive control of defendant coupled with an appreciation of their meaning. Neither the hazards nor the long-term consequences of exposure could be ascertained from the public pronouncements of the United States, oral or written, print or broadcast, issued by the agencies in charge of the testing operations and conducting the Public Safety Program. Even now there are obliterations and excisions in the exhibits which have been filed in this court indicating information still exclusively within defendant's control.

In fact, the public pronouncements made down-played all the hazards. The hazards to these specific plaintiffs in these specific locations are even now denied. Short-term, acute hazards were of some concern but minimized. Long-term world-wide consequences were of some moment but were averaged out. Long-term

hazards and possible biological injury to persons near the site were not addressed at all. No one sues for blisters, visible markings, contemporaneous discomfort, blast-caused or flash-caused conditions of short duration. Each sues for injuries resulting from an internal condition neither early visible nor early detectable.

What is "knowledge" is a question of deep philosophical significance and considered historically has produced a compendium of answers. It implies a knower and the known. It goes beyond simple information to an appreciation of its significance.

Through construction the statute is said to require two things be known with factual and legal sufficiency. First, the injury. Second, the human source of injury.

Here, an apparent illness may in fact be an injury depending on whether a human cause is identified with legal sufficiency.

If the "injury" is cause-dependent, one may not ever know one has been "injured" until cause is demonstrated with legal sufficiency. The usual sequence is upset. The usual sequence of a pellet in the eye, or a sponge in the belly and persuasively pointing to the source—"he did it"—needs be reversed. One may have to point first at a human source to then be able to say with confidence, "I have been injured."

Where latency periods are long for a condition to manifest itself and early on there is genuine doubt as to human cause, reassurances are given by a prospective defendant, and information pointing to human source is essentially unavailable for a long period of time, and the appreciation of the significance of the newly available information is a long time coming, at what point in the sequence in time does an individual plaintiff know enough to compel action? When does he know enough to point to human source and conclude "I have been injured."

May cause, could cause, did cause are different levels of knowing, differing in quantums of information and the appreciation of its significance.

Einstein in St. George could appreciate more from a limited fact base than a lay person listening to the reassurances of his government. That is why each individual plaintiff must be considered part of his individual equation as to running of the statute of limitations. Of course, even then, he cannot shut his eyes to the world. His actual ignorance (lack of information and appreciation of its significance) is tempered by what he should have known.

Illness or injury is person-specific. The nature of an illness or condition is individualized. Levels of knowledge and information about a particular illness and the appreciation of its significance may be markedly different from that of other conditions or illness or injury. The causal connection of one condition may be markedly different from that of another.

Particular levels of knowledge may be tested by the ability of a person to tell someone else what he knows through speech or through writing. This is commonly done in school. When did a plaintiff here know enough to convey sufficient information from one mind to another to show injury and human source? Another method of testing knowledge—the method of science—is to demonstrate, not just with words but by experiments.

At what point in time could a plaintiff show as well as tell?

—During the period of time and shortly prior thereto when additional scientific information and scholarly studies have become available. Tame, neutral information, itself of no great significance, is now looked upon with new eyes in light of expanded knowledge, and the new eyes enable one to appreciate now what one was incapable of appreciating when such information first came to one's attention.

At what point in time does a plaintiff know enough? When can he demonstrate enough to a court to avoid a summary dismissal on the basis of insufficiency? And how long ago was it known? These are significant questions in the opinion of this court particularly when the information relating to cause could earlier have been gathered by the defendant on a person-specific basis. If it had, we would all "know" and know with some confidence.

Again, defendant could contemporaneously have imparted what it now seeks to have retrospectively imputed. No genuine social purpose that I can see is served by the imposing of a procedural bar, the statute of limitations, when the facts of knowledge of injury and human source have been such a long time coming.

The clock of limitations could have started to run a long time ago had the defendant but started it by imparting to the population at risk that which it then knew or had reason—and real opportunity—to know,[92] and which the plaintiffs are just now finding out.

VII. THE DUTY ISSUE

Before the court in a case such as this may reach the question of whether the evidence demonstrates any negligence on the part of the defendant, it must first determine a crucial question of law: whether there exists a legal duty of care on the part of that defendant which extends to the plaintiff. If not, there can be no actionable negligence and no liability. If the court finds that a duty does indeed exist, then the court must determine whether the duty of care owed by the defendant extends to the specific risks that resulted in the plaintiff's injuries. In essence, the court is called upon to define the scope of the law's protection as applied to the facts of the particular case.

In performing this task, the court often has the benefit of guidance from the legislature in the form of statutory language, and from other courts who in the process of deciding prior cases have preserved their reasoning in the form of written opinions. In addition, however, the court is called upon to use its own judgment in evaluating the important ethical, economic, practical and remedial factors—often treated in wholesale fashion as "public policy"—which must be satisfied in every court decision. Finally, the court seeks to do justice between the parties, however "justice" may ultimately be defined. See e.g., Green, "The Duty Problem in Negligence Cases," 28 Colum. L. Rev. 1014 (1928); id. 29 Colum. L. Rev. 255 (1929).

The decision must be made, within constitutional limits,

> whether plaintiff will be granted the legal system's protection—that is, will the defendant be required to have met a specified standard of conduct in the case at issue or be subject to liability. This is a policy decision in purest form. . . .

Thode, "Duty-Risk vs. Proximate Cause, and the Rational Allocation of Functions Between Judge and Jury," 1977 Utah L. Rev. 1, 10 (1977).

The fact that the defendant is the Government does not substantially alter the analysis of the duty issue; indeed, the Federal Tort Claims Act expressly provides that:

> The United States shall be liable, respecting the provisions of this title relating to tort claims, in the same manner and to the same extent as a private individual under like circumstances, but shall not be liable for interest prior to judgment or for punitive damages. . .

28 U.S.C. § 2674 (1982 ed.). With a few exceptions,[93] the duty issue as against the Government is examined in the same fashion as it would be as against the individual or corporate defendant in a negligence action.

In this case, the duty issue must be considered in light of all of the factors mentioned. Determination of the scope of the law's protection in relation to these plaintiffs breaks some new judicial ground. Yet new ground is broken nearly every time a court attempts to match statute, precedent and policy to the particular facts before it. See Green, "The Duty Problem in Negligence Cases," 28 Colum. L. Rev. 1014 (1928). As in many other cases of first impression, existing statutory and case authority offers a foundation upon which to build a rational framework for decision.

The Atomic Energy Act of 1946, Act of Aug. 1, 1946, c. 724, 60 Stat. 755, makes repeated, express reference to the protection of health and safety as a significant goal for activities of the Atomic Energy Commission (AEC) created by that Act. In an effort to promote a program of private and governmental atomic energy

research leading to maximum scientific progress in the nuclear field, the Act provided:

> Sec. 3. (a) Research Assistance—The Commission is directed to exercise its powers in such manner as to insure the continued conduct of research and development activities in the fields specified below by private or public institutions or persons and to assist in the acquisition of an ever-expanding fund of theoretical and practical knowledge in such fields. To this end the Commission is authorized and directed to make arrangements (including contracts, agreements, and loans) for the conduct of research and development activities relating to—
>
> (1) nuclear processes;
>
> (2) the theory and production of atomic energy, including processes, materials, and devices related to such production;
>
> (3) utilization of fissionable and radioactive materials for medical, biological, health, or military purposes;
>
> (4) utilization of fissionable and radioactive materials and processes entailed in the production of such materials for all others purposes, including industrial uses; and
>
> (5) the protection of health during research and production activities.

Atomic Energy Act, § 3(a), 60 Stat. 755, 758 (emphasis added). Section 3(a) goes on to require that "[s]uch arrangements shall contain such provisions to protect health, to minimize danger from explosion and other hazards to life or property. . . as the Commission may determine;. . . " id. 60 Stat. 758-59. Section 4 of the 1946 Act, dealing with the production of fissionable materials, required that

> Any contract entered into under this section shall contain provisions. . . (B) obligating the contractor. . . to comply with all safety and security regulations which may be prescribed by the Commission.

Id. § 4(c)(2), 60 Stat. 759. Section 5, dealing with AEC control of fissionable materials, included a stringent restriction:

> The Commission shall not distribute any material to any applicant, and shall recall any distributed material from any applicant, who is not equipped to observe or who fails to observe such safety standards to protect health and to minimize danger from explosion or other hazard to life or property as may be established by the Commission. . . .

Id. § 5(a)(4), 60 Stat. 761. Section 5(c)(2) makes the same requirement of any distribution of radioactive by-products of fission processes. Similar restrictions are imposed on licensed users of atomic energy technology by § 7(c)(2) of that Act.

Section 6 of the 1946 Act, which concerns military applications of atomic energy, authorized the AEC to "conduct experiments and do research and development work in the military application of atomic energy," and to engage in the production of atomic bombs, atomic bomb parts or other military weapons utilizing fissionable materials" subject to "express consent and direction of the President" obtained at least once a year. Id. § 6(a)(1), (2), 60 Stat. 763. While § 6 is silent on the subject of public safety and health, this does not imply that safety is not an important consideration in nuclear weapons research. Section 6, a bare-bones authorization of activity, is also wholly silent on the subject of secrecy and national security—a major practical concern of the nuclear weapons programs—as well as other important considerations.

Secrecy is dealt with elsewhere in the 1946 Act, as is the general authority of the AEC to regulate atomic activities in the interest of safety:

> In the performance of its functions the Commission is authorized to—
>
> * * * *
>
> (2) establish by regulation or order such standards and instructions to govern the possession and use of fissionable

and by-product materials as the Commission may deem necessary or desirable to protect health or to minimize danger from explosions and other hazards to life or property;

* * * *

Id. § 12(a)(2), 60 Stat. 770 (emphasis added). That the repeated concern for public health and safety expressed in the 1946 Act had direct bearing on nuclear weapons development is highlighted, for example, by a 1954 Senate Committee Report which observes:

It was commonly believed eight years ago that the generation of useful power from atomic energy was a distant goal, a very distant goal. Atomic energy then was 95 percent for military purposes, with possibly 5 per cent for peacetime uses. . . Moreover, there was little experience concerning the health hazards involved in operating atomic plants, and this fact was in itself a compelling argument for making the manufacture and use of atomic materials a Government monopoly.

S. Rep. No. 1699, 83d Cong., 2d Sess. (1954) reprinted in 1954 U.S. Code Cong. & Admin. News 3456, 3458.

The Atomic Energy Act of 1954, Act of Aug. 30, 1954, c. 1073, 68 Stat. 921, codified at 42 U.S.C. § § 2011 et seq., revised and expanded the language of the 1946 act reflecting in part the growing importance of nuclear power development in the AEC program, and in part the perceived need for greater international cooperation on uses of atomic energy. See generally 1954 U.S. Code Cong. & Admin. News 3456 et. seq. (1954). The language of the 1954 Act, as amended, reinforces the concern for health and safety expressed in the 1946 legislation.

In the congressional findings which preface the 1954 Act, it is declared that:

(d) The processing and utilization of source, by-product, and special nuclear materials must be regulated in the national interest and in order to provide for the common

defense and security and to protect the health and safety of the public.

(e) Source and special nuclear material, production facilities and utilization facilities are affected with the public interest, and regulation by the United States of the production and utilization of atomic energy and of the facilities used in connection therewith is necessary in the national interest to assure the common defense and security and to protect the health and safety of the public.

* * * *

Id., § 1, 68 Stat. 921 codified at 42 U.S.C. § 2012(d), (e) (1976 ed.) (emphasis added). The prior concern with health and safety as part of research and development programs was extended to the 1954 Act's new emphasis on peaceful use of atomic energy:

It is the purpose of this chapter to effectuate the policies set forth above by providing for—

* * * *

(d) a program to encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public;

* * * *

Id. § 1, 68 Stat. 922 codified at 42 U.S.C. § 2013(d) (1976 ed.) (emphasis added).

As in the 1946 Act, any arrangements made by the AEC (now the Nuclear Regulatory Commission) concerning research and development as well as production and utilization of nuclear materials "shall contain such provisions (1) to protect health, (2) to minimize danger to life or property, . . . as the Commission may determine." Id. 68 Stat. 927 codified at 42 U.S.C. § 2051(d) (1976 ed.)[94]

On prior occasions the federal courts have held that the decision to conduct a nuclear testing program, including the decision to

detonate a particular device at a particular location, is largely a matter of agency discretion pursuant to the Atomic Energy Act. See e.g., Nielson v. Seaborg, 348 F. Supp. 1369, 1372-73 (D.Utah 1972); Pauling v. McNamara, 118 U.S. App. D.C. 50, 331 F.2d 796 (1964). Yet, as noted in Part V, a rational distinction may readily be made between the policy decision to conduct nuclear weapons testing and the operational considerations that go into the method of conducting a particular test. The Atomic Energy Act of 1954, as amended, authorizes governmental activity in nuclear weapons research while at the same time expressing the intent of the Congress that at the operational level, the AEC should maximize its efforts to mitigate or avoid risks to public health and safety.

At the operational level of nuclear testing activities, the availability of judicial review is manifest. For example, it has already been held that persons residing downwind from the proposed venting of radioactive gases from an underground nuclear detonation have standing under the Administrative Procedure Act[95] to challenge operational activities of the AEC "which allegedly disregard the congressional directive to protect the public health and safety" under the Atomic Energy Act. Crowther v. Seaborg, 312 F. Supp. 1205, 1217 (D. Colo. 1970). See also Nielson v. Seaborg, 348 F. Supp. at 1373. Recent nuclear detonations, particularly the 5-megaton range CANNIKIN test on Amchitka Island in 1971, generated important litigation testing the applicability of the National Environmental Policy Act[96] to those activities. The courts have held that nuclear testing, like other federal agency actions affecting the environment, is subject to the requirements of NEPA; the agency must make an appropriate evaluation of environmental impact before proceeding with tests such as CANNIKIN. See Committee for Nuclear Responsibility, Inc. v. Seaborg, 463 F.2d 788, 796 (D.C. Cir. 1971) injunction denied, 404 U.S. 917 (1971); Aleut League v. Atomic Energy Commission, 337 F. Supp. 534 (D. Alaska 1971). See also Committee for Nuclear Responsibility, Inc. v. Seaborg, 404 U.S. 917 (1971) (Douglas, J. dissenting).

The question relevant to the duty issue in this case is whether the interests asserted by the plaintiffs are protected by the safety

and health provisions of the Atomic Energy Acts, as amended, i.e., whether the acts impose a duty upon the Government in favor of these plaintiffs to avoid the specific risks of injury at issue in this lawsuit. If so, then the next question is whether the acts define a standard of conduct against which the defendant's conduct may be measured.

In Crowther v. Seaborg, 312 F. Supp. 1205 (D. Colo. 1970), the court held that the interests of persons residing downwind from AEC activities in avoiding harmful exposure to radioactive fallout released from an underground test site were sufficiently within the scope of the Atomic Energy Act's protection to afford them standing to challenge the proposed release under the Administrative Procedures Act.

Implicitly, the court in Crowther determined that the Atomic Energy Acts imposed a duty on the AEC in favor of the plaintiffs. That the statute requires at least a minimum standard of conduct is borne out by the court's evaluation of the AEC's activity in reference to that statutory duty.

In an earlier opinion in Crowther affirming the denial of a preliminary injunction, the Court of Appeals for the Tenth Circuit also reviewed AEC plans involving the detonation, concluding that the "Atomic Energy Commission and the other cooperating federal agencies are exercising the highest degree of care, caution and expertise to prevent any possible damage to like property and natural resources." Crowther v. Seaborg, 415 F.2d 437, 439 (10th Cir. 1969)—a tacit recognition of a duty of care where health and safety are concerned.

The plaintiffs in this action assert injury to the same kinds of personal interests arising from agency action, allegedly in derogation of the same congressional directives to protect health and safety. In deciding whether the AEC had breached its duty under the APA standard of review, Judge Arraj considered evidence of the relative risks of radiation exposure that was very much akin to the evidence offered in this case. See 312 F. Supp. at 1220-34.

However, this is not a suit under the APA. To demonstrate the

relevance of a statute as imposing a duty and setting a standard of conduct in a negligence action, one must establish

> (1) the existence of the statute or ordinance, (2) that the statute or ordinance was intended to protect the class of persons which includes the party, (3) that the protection is directed toward the type of harm which has in fact occurred as a result of the violation, and (4) that the violation of the ordinance or statute was a proximate cause of the injury complained of.

Hall v. Warren, 632 P.2d 848, 850 (Utah 1981). See also Dixon v. Stewart, 658 P.2d 591, 600-01 (Utah 1983); Little America Ref. Co. v. Leyba, 641 P.2d 112, 114 n. 3 (Utah 1982); Benson v. Ames, 604 P.2d 927, 929 (Utah 1979); Intermountain Farmers Ass'n v. Fitzgerald, 574 P.2d 1162, 1164-65 (Utah 1978), cert. denied 439 U.S. 860; Thompson v. Ford Motor Co., 16 Utah 2d 30, 395 P.2d 62 (1964); 1954 Wis. L. Rev. 116-17. A sensible reading of the Atomic Energy Acts readily proves (1) and (2); the type of harm alleged by the plaintiffs, i.e. physical injury resulting from exposure to ionizing radiation, is precisely the type of harm that the requirements and guidelines of those acts were intended to minimize as a protection for downwind residents and the general population. (Whether there was a violation of the statutory duty that proximately caused the plaintiffs' injuries and losses remains to be determined. See Part VIII, infra.) Although the criteria set forth by Hall v. Warren and related cases are generally applied to state statutes and local ordinances, no compelling reason presents itself which would justify exclusion of a federal statute which meets the criteria, particularly in the context of the Federal Tort Claims Act. The FTCA in hybrid fashion applies state tort law to judge conduct of governmental agencies and employees whose activities and duties will most often be defined initially by federal statute or regulation.

In Crowther, the court found that promulgation and enforcement of adequate radiation protection standards by the AEC adequately defined the scope of the AEC's duty under the relevant acts. The duty imposed upon the Government in this action is at least as extensive as that in Crowther. It is the same basic duty of care

owed to a similar group of people. In the context of a negligence action, it may well be determined that the law imposes additional duties upon the defendant by virtue of the nature of its conduct toward the plaintiffs. Or it may not. At a bare minimum, however, the duty of care imposed by the Atomic Energy Acts establishes that some legally significant relationship exists between the defendant and the plaintiffs in this action.

Once a duty of care has been established, the "standard that the defendant must have met in the case to avoid potential liability has to be determined." Thode, "Duty-Risk vs. Proximate Cause and the Rational Allocation of Functions Between Judge and Jury," 1977 Utah L. Rev. at 1, 10. This standard may vary from one approaching the strict liability often imposed on those engaged in ultrahazardous activities to one of simple negligence, one which focuses on the reasonableness of defendant's conduct under the circumstances, or a gross negligence standard, which imposes liability only for actions bordering on the reckless.

In this case a number of factors will be considered in determining the appropriate standard of conduct. One factor is the statutory duty. In Crowther, for example, the court considered an attack on the adequacy of AEC safety rules in light of the following standard:

> All that is required to establish reasonableness of the decision setting a standard under the statutory directive to protect the public health and safety is that it be made carefully in light of the best of available scientific knowledge. Absolute certainty is neither required nor possible.

Crowther v. Seaborg, 312 F. Supp. at 1234 (emphasis added). The standard of conduct "carefully in light of the best of available scientific knowledge" as a measure of defendant's statutory duty may prove to be appropriate in this case as well.

Under Utah law, "[a]s a general rule, violation of a standard of safety set by a statute or ordinance is prima facie evidence of negligence." Hall v. Warren, 632 P.2d at 850. Identification of a relevant safety statute does not end the inquiry as to the scope of

defendant's duty to plaintiff or the appropriate standard of conduct; it provides evidentiary guidance in aid of the court in applying the traditional common-law analysis of duty, breach of duty, and liability:

> While in some jurisdictions, violation of a statute designed to protect those in the plaintiff's position from the type of injury incurred by the plaintiffs as a result of defendant's action establishes negligence as a matter of law, in Utah, such violation is prime facie evidence of negligence only. This means, in essence, that the standard of conduct prescribed by the statute does not supplant the usual standard of careincumbent upon the individual involved. . . , but is merely probative of the defendant's compliance or non-compliance with that standard. As such, even given a statutory violation, the negligence or non-negligence of the defendant remains an issue for the trier of fact. . . .

Benson v. Ames, 604 P.2d 927, 929 (Utah 1979) (emphasis added & footnotes omitted).

A number of factors bear upon the question of the issue of standard of care. The significance of the risks created by the defendant's conduct and the relative utility of measures which minimize or mitigate those risks are important considerations. As Cardozo instructs us, "The risk reasonably to be perceived defines the duty to be obeyed,. . . " Palsgraf v. Long Island R. Co., 248 N.Y. 339, 162 N.E. 99, 59 A.L.R. 1253 (1928); "the orbit of the danger as disclosed to the eyes of reasonable vigilance would be the orbit of the duty." This holds true not only in determining to whom the defendant's duty of care reasonably extends, but also in determining the degree of care to be exercised. In Meese v. Brigham Young University, 639 P.2d 720 (Utah 1981), the Utah Supreme Court highlights an important corollary to the reasonable man standard: "[i]n the exercise of ordinary care, the amount of caution required will vary in accordance with the nature of the act and the surrounding circumstances." 639 P.2d at 723.

Under Utah law, the standard of conduct to be attained ordinarily is that expected of the reasonable man, i.e., the standard

of reasonable care under the circumstances.

> This court has defined negligence as a failure to exercise the degree of care which a reasonable person would have exercised under the same circumstances, whether by acting or by failing to act. . . . The care to be exercised in any particular case depends upon the circumstances of that case and on the extent of foreseeable danger involved and must be determined as a question of fact.

DCR, Inc. v. Peak Alarm Co., 663 P.2d 433, 434-35 (Utah 1983) (footnote omitted). What is "ordinary" under the most extraordinary of conditions, however, is dictated by those conditions.

What is "ordinary care"—what is "reasonable"—in the handling of the repeated release of huge quantities of the most toxic materials known to man directly into the environment? The Crowther standard requiring agency decisions to be made "carefully in light of the best of available scientific knowledge" readily lends itself to the evaluation of conduct which generates the kinds and quantities of radioactive materials we are concerned with in this case. Atmospheric nuclear testing has expelled more radioactive material into the world under far less human control than any other human activity to date. Finding a small corner of the earth which as yet remains wholly untouched by radioactive fallout would be more than a match for even the most seasoned of explorers.[97] Ounce for ounce, the risks associated with that dispersal are far greater than the relative risks of any other human enterprise. Extraordinary risk demands extraordinary care.

The standard of care, of course, is tempered in this case[98] by the limits of human control. Once loosed in the air, the nuclear fireball engulfs and annihilates the devices of direct restraint and control available to humans; its cloud of lethal debris may be predicted, traced and monitored, but it is never confined. Failure to prevent the inevitable may not be negligence. Failure to take the best, most stringent protective measures to warn of, lessen, and mitigate its risks may very well be negligence.

One important source of practical guidance in setting standards

of conduct is the standard of care established and applied by government nuclear laboratories apart from the Nevada Test Site. It is one thing if responsible persons at Oak Ridge, or Hanford, or Los Alamos react with indifference to all but the most acute radiation exposures; it is quite another if in these laboratories, where much smaller quantities of material are much more easily controlled, all leakages and exposures are painstakingly monitored and analyzed in an effort to keep risks as low as is reasonable achievable. If stringent care is exercised, for example, in monitoring and confining curies quantities of radioactive material escaping into the ponds near Oak Ridge, why should not at least as much care be exercised in dealing with the megacuries of radioactivity in the pink-orange clouds of dust, gases and ash drifting eastward from southern Nevada? The safety standards of the nuclear research community provide important background and landmarks for evaluation of conduct as have the "community standards" of practice of other professions in other cases defining appropriate standards of care[99] While certainly the "laboratory" functions of the Nevada Test Site differ considerably from those of the other AEC research facilities, the risks created by materials under study differ only in degree, not in kind. The value of nuclear community practice is further enhanced by the common control exercised during the relevant time periods by the AEC. Each was an arm of the same government.

Other considerations counsel in favor of a strict reading of the "reasonable man" standard: for one thing, the Government cultivated a virtual monopoly of nuclear information pursuant to the language of the Atomic Energy Act. Many of the most important exhibits in evidence before this court find their source in the Government records. Almost all of those have had their "classified," "restricted," or "top secret" lables only incompletely scratched out or removed. Even now, a number of documents have been prepared with incomplete information. See e.g., H. Hicks, "Results of Calculations of External Gamma Radiation Exposure Rates . . . Operation Upshot-Knothole, (1953)," at 2 (Lawrence Livermore Nat'l Lab. July 1981 DX-1163. ("The [uranium and plutonium] data were omitted primarily to keep the output unclassified.") Where risk-creating conduct is concerned, the party having superior knowledge of the specific conduct and the particu-

lar risks created has been held to a stricter standard of care than the defendant who shares common knowledge and understanding of the risks with the plaintiff and others.

The law expects people to take actions on their own to protect themselves from evident and obvious dangers. Ordinarily one has a duty to do so. See e.g., Pollesche v. K-Mart Enterprises of Utah, 520 P.2d 200 (Utah 1974); Whitman v. W. T. Grant Co. 16 Utah 2d 81, 395 P.2d 918 (1964). This duty extends to dangers which are foreseeable as well as those which are immediate and unforeseen. A plaintiff's failure to foresee a danger which a reasonable person acting in a prudent manner would have foreseen is itself negligence which may bar the plaintiff from legal remedies. See e.g., Moore v. Burton Lumber & Hardware Co., 631 P..2d 865 (Utah 1981). This common duty, however, does not extend to dangers which are latent, hidden, invisible or otherwise beyond the scope of the ordinary person's powers of observation.

Even in dealing with radiation hazards, the law makes a distinction between cases in which the parties share equal technical knowledge of the particular danger, and cases in which they do not. See e.g., High Voltage Engineering Corp. v. Pierce, 359 F.2d 33, 35 (10th Cir. 1966). Prosser instructs that if the defendant has "knowledge, skill or even intelligence superior to that of the ordinary man, the law will demand of him conduct consistent with it." W. Prosser, Handbook of the Law of Torts § 32 at 161 (4th ed. 1971); The Restatement (2d) of Torts § 289, comment m (1965) observes that if an actor possesses more than the minimum of perception, knowledge, intelligence, etc., "he is required to exercise the superior qualities that he has in a manner reasonable under the circumstances. The standard becomes, in other words, that of a reasonable man with such superior attributes." (Emphasis added.)

The rule is grounded upon common sense: the party with superior knowledge is in the better position to lessen or mitigate the risks of injury. As far as nuclear fallout is concerned, the Government possessed an overwhelming superiority in knowledge, as well as an effective monopoly of the special skills, training and experience relevant to open-air atomic testing.

The immediate danger, i.e., exposure of humans to ionizing radiation, involves direct contact with the invisible. Alpha particles, beta particles and gamma rays fall beyond the range of human senses. Specialized instruments or materials must be used to detect their presence. Those without special technical skills are hard pressed to exercise the degree of care needed to protect themselves from such a hazard. A stringent duty of care to minimize such hazards is deliberately imposed on the party who acts with vastly superior knowledge, in favor of those having less information. The information gap between the plaintiffs and the Government in this action approaches the absolute; a duty of care adjusted according to that vast difference is very stringent duty indeed.

Another reason for inposing a high standard of care is supplied by precedent: in dealing with conduct of potential danger to children, there is a duty to observe extra caution for their safety. See e.g., Rivas v. Pacific Finance Co., 16 Utah 2d 183, 397 P.2d 990 (1964). Of course, children are less able to understand even commonplace risks than are adults. This is one justification for increased care. In this case, however, it has long been recognized that exposure to ionizing radiation inherently creates an increased risk of injury to children because of their greater sensitivity and vulnerability to radiation damage. See Part IX, infra. It was suggested during the open-air testing program, for example, that exposure limits for children be reduced to one-tenth of the adult limits. See e.g., Memorandum, Lt. Col. R. Campbell to Gn. K. Fields, May 8, 1953, PX-90.

The evidence now available simply confirms the early hypotheses of increased risks to children arising from radiation exposure. See e.g., J. Gofman, Radiation and Human Health (1981), PX-1046; Part IX, infra. Under Utah law, as in most American jurisdictions, increased risk of injury imposes a greater duty of care on the party who creates the risk. See e.g., Black v. Nelson, 532 p.2d 212, 213 (Utah 1975); Erickson v. Bennion, 28 Utah 2d 371, 503 P.2d 139 (1972); Brigham v. Moon Lake Electric Ass'n, 24 Utah 2d 292, 470 P.2d 393 (1970).

The weighing of these factors, i.e., the relative degree of risk of serious injury, the tremendous imbalance of knowledge and skill,

the increased hazard to children, accompanied by the increasing foreseeability of the potential hazards, see Part VIII, supra, readily leads one to conclude that the appropriate standard of care must be one requiring great caution. This court now holds that in its conduct of open-air atomic testing, and in its offsite radiation safety programs—including its public information activities—the Government was bound by a legal duty to act with the highest degree of care in light of the best of available scientific knowledge. Government employees need not have been perfect. But the course of action followed must have been that most protective of health and safety if the requisite standard is to be met.

Defendant's duty, of course, varies according to the state of available scientific information at a given time. The exactness of hindsight is not the appropriate measure of foreseeability or degree of care. But those responsible for safeguarding the public health and safety are charged with the duty to anticipate risks of injury reasonably inferable from the available information.

No one, including the officers and employees of government, can be expected to guard against risks of harm which are not to be rationally anticipated, or which are so unlikely to cause injury that they may be reasonably disregarded. Yet mathematical probability is not the ultimate test of foreseeability, duty or negligence:

> [I]f the risk is an appreciable one, and the possible consequences are serious, the question is not one of mathematical probability alone. The odds may be a thousand to one that no train will arrive at the very moment that an automobile is crossing a railway track, but the risk of death is nevertheless sufficiently serious to require the driver to look for the train. It may be highly improbable that lightning will strike at any given place or time; but the possibility is there, and it requires precautions for the protection of inflammables. As the gravity of the possible harm increases, the apparent likelihood of its occurrence need be correspondingly less.

W. Prosser, Handbook of the Law Torts § 32 at 147 (4th ed. 1971) (footnotes omitted). Probability of injury is only one of many

elements to be evaluated in the duty/breach of duty analysis. It is a factor of varying significance.

Where the Government undertook to test, to monitor, to warn and to protect, it did so according to its duty to act with great care. It did so with the vast storehouse of data and analysis at its disposal. It undertook those tasks with the full-fledged, constant legal duty to avoid injury or death arising from its own negligence.

A number of contemporaneous documents disclose that the Atomic Energy Commission was conscious of its duty to protect health and safety from the beginning of the continental testing program. AEC Meeting No. 624, held on November 7, 1951, topics discussed included "the acceptability of recognizing complete military responsibility for the conduct of [weapons] effects tests within the continental U.S., in view of the responsibilities of the Commission for such aspects of a test as the utilization of fissionable material and for radiological safety." Memorandum, (Nov. 7, 1951), DX-235; complete responsibility was never relinquished by the AEC. To the contrary, compliance with AEC safety criteria was expected in every test series, and the subject of hazard from fallout was a recurring concern of Commission members. See e.g., Minutes of AEC Meeting No. 541, March 26, 1951, DX-527; Minutes of AEC Meeting No. 584, July 27, 1951, PX-409/DX-95; Minutes of AEC Meeting No. 654, Jan. 23, 1952, PX-1030; Minutes of AEC Meeting No. 863, May 18, 1953, DX-166; Minutes of AEC Meeting No. 865, May 21, 1953, DX-165; Minutes of AEC Meeting No. 962, Feb. 17, 1954, DX-32; Minutes of AEC Meeting No. 1062, Feb. 23, 1955, DX-328; Minutes of AEC Meeting No. 1020, Aug. 18, 1954, DX-56, 324; Minutes of AEC Meeting No. 1252, Dec. 5, 1956, DX-374, at p. 765 ("[A]lthough the figures used at NTS are conservative, an improved and expanded monitoring program should be conducted in the communities surrounding NTS." [comment of W. Libby]). In a May 28, 1953 meeting with the Military Liason Committee, Gen. K. E. Fields of AEC commented that the Commission operated "on the principle that it has no right to subject the public to the radiation permitted for its own employees," and certainly not more. Minutes of 81st Conference, AEC-MLC, May 28, 1953, DX-566, at 2. When two months later, concern was expressed "that the Commission might have under-

estimated the seriousness of the fallout problem" Commissioners Henry Smyth and Eugene Zuckert countered that "there has been no disposition on the part of the Commission to think that the problem was not a most serious one." Minutes of AEC Meeting No. 884, July 7, 1953, DX-163.

Other documents and testimony in the record also attest to the Atomic Energy Commission's abiding concern for its "obligation" and its "responsibility" for public safety. Even had the record been wholly silent on this subject, the law would nevertheless impose a stringent duty of care upon the defendant, as it certainly would upon a private individual releasing megacuries of radioactivity into the air. The record, however, is not silent; responsibility, obligation—duty of care was acknowledged and accepted from the beginning.

The only remaining questions relating to the duty issue are (1) whether the particular risks which have taken effect in the alleged injuries to the plaintiffs fall within the scope of the defendant's duty of care; and (2) whether the defendant's conduct breached that duty.

The risk that off-site residents near the Nevada Test Site might develop cancer or leukemia following exposure to ionizing radiation from nuclear fallout in amounts significantly in excess of normal background radiation was one well within the scope of the Government's duty of care, perhaps even closer to the core of that duty than the risks of purely acute injury; the claims litigated in this action deal with injury and loss far more serious than reddening of skin or temporary loss of hair due to acute exposure. If it can be established that the Government negligently or wrongfully breached that duty, and that a rational factual connection exists between the Government's conduct and the plaintiffs' injuries, then law and public policy[100] require that liability be imposed upon the party creating this particular risk. Even where there remains the possibility that the injury would have occurred in the absence of defendant's conduct—which is always a possibility in every case of cancer or leukemia—doing justice between the parties requires that the party creating a materially increased risk of that harm bear at least the economic burden of its consequences.

Where by a preponderance of the evidence, the plaintiffs establish that the defendant's conduct negligently or wrongfully breached the duty of care, and that the conduct materially augmented or increased the risks of injury, and contributed to the harm suffered by the plaintiffs, the defendant shall be held liable.

VIII. BREACH OF DUTY

A. State of Scientific Knowledge

In holding that the Government is bound to exercise "great care in light of the best of available scientific knowledge," one necessarily must determine what the best of available scientific knowledge was during the period between 1951 and 1962. Knowledge and information was not constant; it was persistently expanding during those years and has continued to grow ever since. Consequently, the conduct of those who were responsible for public health and safety on the operational level must be measured against a standard of care that grew more stringent as time passed.[101]

Since the discovery of x-rays and naturally radioactive elements near the turn of the century, information about radiation and radiation effects accumulated rapidly. Those who worked too closely to the early x-ray tubes quickly experienced some of the acute effects of radiation exposure. See e.g., O. Glasser, Dr. W. C. Roentgen 41-52, PX-629; "The Roentgen Ray, and its Relation to Physics," Transaction of the Amer. Inst. of Electrical Engineers, Vol. XIII, 403, 418 (1897), PX-630. Over a period of time, numerous instances of injury and illness were observed among scientists, technicians and others working with x-rays or radium. In 1913, a set of radiation protection rules were formulated in Germany in recognition that "[r]epeated radiation of any part of the human body with x-rays is dangerous and has on many occasions already led to severe injury and even to death among radiologists." The German publication, "Merkblatt 1913 der DRG, uber Schutzmassregeln gegen Roentgenstrahlen," further advised that every person involved in radiation work "has the right to refuse radiographic work if the protection arrangements are inadequate. Such refusal shall never constitute grounds for dismissal." Id. Engl. trans.

quoted in L. Taylor, Organization for Radiation Protection: The Operations of the ICRP and NCRP 1928-1974 (1979) DX-693, at 1-001, 1-002.[102]

In 1915, the Roentgen Society in England observed that "[t]he harmful effects produced by x-rays are cumulative and do not generally appear until some weeks or months after the damage has been done. It is to be noted that x-rays of any degree of hardness are capable of producing ill effects. . . " Quoted in Id. DX-693 at p. 2-003. During the 1920s, the British organizations made significant efforts to establish controls for use of radiation and radioactive materials.

A number of researchers from several nations sought to define an acceptable "tolerance dose" below which exposures should be kept. Formal efforts in that direction began at the international level in 1925. In a 1931 report to the League of Nations, Wintz and Rump observed that

> In the therapeutic application of radiation, the idea of the tolerance dose is a current notion. It signifies the amount of radiation which the tissue concerned is still able to tolerate. Experience has shown, however, that such a dose cannot be regarded as entirely harmless; for even though, after its administration, the tissue undoubtedly undergoes none of the morphological alterations which are known as Roentgen injuries, yet it is left with a reduced power of resistance to otherwise inoperative influences. . . .This holds good for all kinds of tissue, even through the radio-sensitivity, and thereby the tolerance dose, differs for each.
>
> The above observations show that the tolerance dose is never a harmless one and that tolerance doses can in no case be readministered indefinitely to any particular piece of tissue after the visible effects have disappeared on each occasion.
>
> The only dose, therefore, that could be harmless, would be one which would produce no effect whatever, on the particular piece of tissue concerned. . .

Quoted in L. Taylor, Organization for Radiation Protection, DX-693, supra at pp. 3-024, 3-025 (emphasis added). Wintz and Rump further stated that "the exact determination of such a [harmless] dose would seem to be impossible." Id..

Organizational efforts to control radiation hazards in the United States commenced in 1929. A tolerance dose standard for radiation workers of 0.1 Roentgen per day was established in 1936. Id. at 4-001 et seq.; 5.001 et seq. Soon, however, evidence of genetic changes resulting from ionizing radiation developing in the work of Muller[103] and others moved the Advisory Committee on X-Ray and Radium Protection to consider reduction of the tolerable dose by a significant amount:

> With regard to the genetic effects of x-rays, it was agreed that genetic effects of some order are produced for any size dose, and therefore there is a valid question as to whether a further factor of 10 is vitally important from a genetic protection point of view.

Minutes of Meeting, Sept. 25, 1941, quoted in id. DX-693 at p. 5-019 (emphasis added). At the same meeting, another important question was discussed:

> At this juncture, it was pointed out that much confusion existed, not only in our own discussions, but in the mind of the radiologist and the layman through use of the term "tolerance dose." The implication is that the tolerance dose is one which can be tolerated without any damage whatever, which, of course, is not the case if we consider genetic damage. It was recommended therefore that in the future we use the term "permissible dose." This does not in any way imply that no injury will follow. It merely says that the Committee recommends its use even though it is not necessarily safe, but is adopted only as a practical and expedient value.

Id. at p. 5-020 (emphasis added). Further discussion was postponed until after World War II, until the efforts were renewed by the newly formed National Committee on Radiation Protection (NCRP) in 1946. Soon its subcommittees on radiation exposure

recommended reduction of the "permissible" external gamma dose for radiation workers to 0.3 rads per week: "In light of our present knowledge, it is assumed that exposure of the whole body to penetrating x-rays at the rate of 0.3 R per week over a period of many years does not increase perceptibly the incidence of leukemia." Id. DX-693, at p. 7-040. At the same time, committee members stated "it is well to point out that the permissible limits given here are maximum values. In practice every effort should be made to maintain the actual exposures considerably below these limits." Id. DX-693, at p. 7-042 (emphasis in original). The reduced limit was soon adopted by the NCRP, and ultimately by its international counterpart, the International Commission on Radiological Protection (ICRP), in 1950. Id. DX-693, at pp. 7-210 through 7-212. In doing so, the ICRP commented:

> Whilst the values proposed for maximum permissible exposures are such as to involve a risk which is small compared to the other hazards of life, nevertheless in view of the unsatisfactory nature of much of the evidence on which our judgments must be based, coupled with the knowledge that certain radiation effects are irreversible and cumulative, [i]t is strongly recommended that every effort be made to reduce exposures to all types of ionizing radiations to the lowest possible level.Id.

DX-693, at p. 7-211 (emphasis added).

Hard evidence of low-level radiation resulting in harmful somatic and genetic effects in humans was scarce at that time, particularly in terms of long-term consequences. There were, of course, many earlier studies of large doses of x-rays, as well as the incidence of cancer and leukemia among persons who had worked as luminous watch dial painters and had ingested lethal quantities of radium in the process. Some statistical information concerning the relative life span of radiologists had been compiled and analyzed. Numerous animal studies had been done; others were underway. See e.g., H. Martland, "The Occurrence of Malignancy in Radioactive Persons," 15 Am. J. Cancer 2435-2516 (Oct. 1931), PX-868; Pfahler, "The Development of Roentgen Therapy During Fifty Years," 45 Radiology 503 (Nov. 1945), PX-633; Larks,

"Strong X-rays from Electron Beam Instruments and Some Biological Implications," 12 Am. Ind. Hyg. Assoc. Quarterly 176 (Dec. 1951), PX-652; see also Simpson & Hempelmann, "The Association of Tumors and Roentgen-Ray Treatment of the Thorax in Infancy," 10 Cancer 42-56 (Jan. 1957), PX-623.

By 1950, however, the concept that genetic alterations occurred at any dose of radiation went essentially undisputed among those concerned with radiological protection. While hard experimental evidence of somatic effects, especially cancer and leukemia, of exposure below the "permissible" limits of 0.3 R per week were largely lacking, potential risk was not ignored. The philosophical approach taken by groups such as the NCRP is instructive:

> For perhaps the first three decades after the discovery of x-rays and other ionizing radiations, it is probable that there was thought to be some definite threshold of radiation dose that a person might receive, above which there would be some effect and below which there was probably no such sharp dividing line between "effect" and "no effect" and even if there was, the exact determination of such a dose would seem to be impossible (Wintz and Rump, 1930). The tolerance dose concept, introduced in 1925, and which prevailed for the next fifteen or twenty years was not intended to imply the existence of a strict threshold but was the indication of a level of exposure below which "no alteration in the condition and activity of the body can be detected by available methods of clinical examination and observation." It must be clear that if there is no threshold there must indeed be some degree of effect for any radiation exposure whether or not it can be detected and whether or not it may be regarded as deleterious or harmful.
>
> If for any dose of radiation, however small, it is assumed that there is some effect which is regarded as carrying or producing some harm, again however small, it must follow that any exposure to radiation has associated with it some element of risk. The general enunciation of the risk philosophy was first put forth by the National Committee on Radiation Protection in its Report No. 17 complete in 1949 and

published in 1954. This report stated, "It is, therefore, necessary to assume that any practical limit of exposure that may be set up today, will involve some risk of possible harm. The problem then is to make this risk so small that it is readily acceptable to the average individual; that is, to make the risk essentially the same as is present in ordinary occupations not involving exposure to radiation." It went on further to say, "In connection with the protection problem there has been a tendency in the past to assume any detectable biological change produced by radiation is deleterious. This conservative attitude is desirable in the absence of conclusive evidence to the contrary."

Id. DX-693, at p. 10-211 (emphasis added).

Indeed, "this conservative attitude" has proven very worthwhile.

At no time from 1951 through 1962 did the NCRP embrace the threshold hypothesis in assessing the risks resulting from ionizing radiation.

By the mid 1950's, there was increasing concern about possible effects of very low levels of radiation exposure, such as might be encountered by fall-out from the testing of nuclear weapons. With this in mind, in 1958 the NCRP established a special Committee under the chairmanship of Dr. Hymer Friedell to examine the problem of exposure of the population to man-made radiation from the point of view of somatic effects as distinct from genetic effects. (See Appendix I for excerpts from the full report.) One of the most important conclusions of the Committee follows: "The Committee believes that present evidence is not sufficient to establish the dose-response curve for somatic effects at low doses. In the absence of such information, the Committee has chosen to make the cautious assumption that there is a proportional relationship between dose and effect and that the effect is independent of the dose rate or dose fractionation." This assumption is what is now commonly referred to as the nonthreshold, linear dose-effect relationship, which for over a decade has served for discussions and the estimates of

> possible upper limites of radiation injuries from chronic low level exposures.

Id. DX-693 at p. 10-211 (emphasis in original). While the AEC was not legally bound to follow the views of the independent NCRP, the AEC was certainly aware of NCRP standards and philosophy and placed considerable reliance upon those standards. In relying upon an exposure standard of 0.3 R per week, one was bound to give some credence to the warning that compliance was no guarantee of "no injury." See e.g., id. DX-693 at 8-198B (AEC Commissioner W. R. Libby). That a permissible dose "is not expected to cause appreciable bodily injury," id. DX-693 at p. 7-286, was never intended as a promise that none would ever occur. In making recommendations concerning exposure of the general public, the NCRP went on record as stating that a level that would avoid "unacceptable" somatic injury among the population would be 1/10th of the occupational level. See id. DX-693 at 8-169. By 1959, the NCRP Ad Hoc Committee on Population Exposure tightened that recommendation to a level that was 1/10th of natural background radiation, based upon the cautious assumption noted above, i.e., of a linear, non-threshold dose-response relationship. Id. DX-693, at pp. 8-188 through 8-216; App. P.

Caution was not the exclusive province of the NCRP or similar groups. Shubert and Lapp, in a 1957 book entitled Radiation: What It Is and How It Affects You, point out that

> A radiation limit, therefore, is not to be regarded as a kind of traffic speed limit. The 0.3 r per week does not correspond to a 25-mile-per-hour limit on a city street. To use the language of traffic regulations, the radiation safety rule is "Go as slowly as possible."

J. Shubert & R. Lapp, id. at 43.

Years before, the potential genetic risks which were the subject of such concern were a matter of textbook knowledge—for those pursuing professional training in the field. In discussing the relative safety of the then-extant 0.1 r per day standard, Pollard and Davidson in 1942 cautioned students as follows:

> The final word of caution we wish to write concerns genetic changes. The exposure of an individual to radiation automatically renders him liable to suffer a mutation, and there is no threshold to the radiation dose which will produce the change. It is just a gamble. There is thus no safe dose that can be prescribed:. . .

E. Pollard & W. Davidson, Jr., Applied Nuclear Physics 168 (1942) (emphasis in original). Training manuals prepared for workers at the Nevada Test Site express similar caution about genetic effects. E.g., F. Wilcox, ed., "Basic Radiological Safety Training Manual," Reynolds Elec. & Eng. Co. (1957), Unit 10 (W. Johnson), DX-700.

While experimental evidence demonstrating the degree of risk of somatic effects of lower radiation levels was more scarce, confidence in expressed exposure standards was commonly tempered with the cautious view that the growth of experience with radiation might disclose effects, especially induced cancer and leukemia, not previously observed over short periods. The stream of information flowing from study of the survivors at Hiroshima and Nagasaki accented this concern in the early '50s, as did the growing body of animal research data. From the preponderance of the historical and scientific materials now and before this court, the conclusion appears inescapable that a reasonable person, exercising great care in light of the best of available scientific knowledge, would err on the side of caution by assuming no "safe" threshold exposure to atomic radiation, i.e., that any degree of exposure equates with some corollary degree of biological risk, and by determining that every practicable step be taken to minimize unnecessary radiation exposure. The reasonable man would not, therefore, conclude if radiation dosage is kept at near the "maximum permissible" limits suggested by the NCRP, the ICRP or others, there is no increased risk of injury. Even the choice of the term "permissible" dose rather than "tolerance" or "safe" dose was made deliberately to avoid such inference. The exposure limits discussed above reflect in part the limits of available scientific evidence demonstrating somatic effects of radiation as that data stood in the late 1940s. The line drawn at 0.3 rad per week (or 3.9 R in 13 weeks) was no brightline test distinguishing risk versus no risk; it demarcated the difference in degree of risks accepted by

those who chose to work in irradiated jobs. It marked that which in the long run cost something in contrast with that which, by concensus of many experts, cost too much.

It is important to point out that exposure standards such as those promulgated by the NCRP were not designed for evaluating nuclear fallout; they were intended to protect those who chose to pursue occupations in the medical, scientific or industrial fields in which radiation exposure was a known fact of life. Likewise, it is important to note that the exposure standards utilized in offsite monitoring programs at the Nevada Test Site were more or less equivalent to those applied to workers in the industry. The 0.3 rad per week standard (3.9 rad in 13 weeks), applied in the early test series detonations, was tightened in 1955 by a factor of 4:

CRITERIA VI
Routine Radiation Exposure

> The whole-body gamma effective biological dose for offsite populations should not exceed 3.9 roentgens over a period of one year. This total dose may result from a single exposure or a series of exposures.

"AEC Radiological Safety Criteria and Procedures for Protecting the Public During Weapons Testing at the Nevada Test Site," at 10 (Feb. 1955) DX-689. It should be noted that the "effective biological dose" to the offsite population was the product of reducing the measured dose[104] or the "theoretical" dose derived from integrated dose readings by a "multiplication factor" of 3/4 or 1/2, to account for the difference between the measured dose "and that received at the tissue depth of five centimeters," or about two inches. No such multiplication factor is included by the NCRP in its guidelines for radiation workers. See L. Taylor, Organization for Radiation Protection, supra, DX-693 at 8-082 to 8-085. What is unusual or special about tissue at the 5 cm. level is not explained. Furthermore, in other AEC activities as early as 1947, the agency had applied the other 0.1 rad per day standard, directing that "[n]o individual shall knowingly expose himself or cause others to be exposed to greater than this quantity in any 24 hour

period." AEC Isotope Branch Circular B-1 (August 1947), quoted in Taylor, supra, DX-693 at 7-026. "It is advisable," observes that early circular, "to strive for the lowest possible daily total exposure in every operation." Id. Criteria VI, quoted above would seem to permit much more: all 3.9 R may be the product of a single exposure.

Yet those with expertise in the field of radiation protection have consistently recognized significant factors which differentiate the risks to radiation workers from risks to the general public: (1) when the general public is considered, a larger number of people are at risk: a given exposure rate will result in larger real numbers of injuries; (2) employment in radiation work is voluntary, and the extent and nature of exposure and risk can be evaluated by the worker against direct personal benefits; (3) radiation workers are individually screened and monitored on a person-specific basis for exposure in a controlled environment; (4) children, while not permitted to work in the atomic industry, are placed at particular risk when the whole community is exposed to ionizing radiation; and (5) subjecting a population to increased environmental radiation results in longer periods of exposure than in most occupational settings.

These policy factors are not new. They were the subject of regular discussion among those concerned with radiation safety since the 1930s. Special problems concerning children, for example, were often noted. See e.g., L. Taylor, Organization for Radiation Protection, supra, DX-693, 7-039, 7-263, 8-042; Miller, "Safeguarding Children from Radiation Risks," U. S. Dept. of HEW, (1956), DX-643. These factors are the same ones considered by the 1959 NCRP Ad Hoc Committee in suggesting that standard for population exposure should be a minor fraction of background radiation dosage. See L. Taylor, supra, DX-693 at App. P.

At the very least, it seems logical that if populations—particularly localized communities—are to be placed at risk approaching that experienced by radiation workers, they should be adequately informed of those risks. This would enable them to decide whether other compensatory benefits make tolerable the increased degree of risk resulting from radiation. If the risks are to

be similar, those who are in the position to do so would be charged with the specific duty of monitoring actual exposure of persons on an individual basis, or at least with enough precision and continuity that individual exposures may be determined accurately. Recalling the very tentative nature of the dosage standards, and the repeated emphasis upon keeping exposures as low as possible, measures would need to be taken to minimize external and internal radiation exposure where it is possible to do so. The effort to inform, to monitor, to record and to minimize hazard, would be redoubled where the health and safety of children is in question.

A good deal was known about radiation during the period that open-air nuclear testing was conducted. Concerning the somatic effects of low dose levels, there was considerable uncertainty. There still is. See Part IX, supra. The reaction among health physicists and others skilled in the nuclear sciences in the face of such uncertainty has been caution, a deliberate avoidance of risk when risk may practically be avoided.

That detonation of a nuclear weapon would generate a hazardous and potentially lethal cloud of radioactive debris was never a surprise. In 1940, physicists Otto Frisch and Rudolph Peierls collaborated on the calculation of the first mathematical model of a practical fission device using uranium-235. In a memorandum to the British Air Ministry "On the Construction of a 'Super-bomb': Based on a Nuclear Chain Reaction in Uranium," the two physicists predicted that the radioactive products of fission "will probably be blown into the air and carried away by the wind."

> This cloud of radioactive material will kill everybody within a strip estimated to be several miles long. If it rained the danger would be even worse because active material would be carried down to the ground and stick to it, and persons entering the contaminated area would be subjected to dangerous radiations even after days. If one percent of the active material sticks to the debris in the vicinity of the explosion and if debris is spread over an area of, say, a square mile, any person entering this area would be in serious danger, even several days after the explosion.

Id., Frisch-Peierls Memorandum, Part I, p. 3, File AB 1/210, Public Record Office, Kew, London, quoted in R. Clark, The Greatest Power on Earth 90 (1980). When one considers the physics of the fission process, see Part II(G), supra, the conclusion that detaonation of a nuclear explosion will yield tremendously radioactive debris is inevitable. See Part III(A), supra.

In dealing with nuclear fallout, there existed in 1951 a body of specific information and experience derived from the TRINITY test at Alamagordo, New Mexico, the Hiroshima and Nagasaki detonations in 1945, and the ABLE (23 kt), BAKER (23 kt), X-RAY (37 kt), YOKE (49 kt) and ZEBRA (18 kt) detonations at Bikini and Eniwetok Atolls in the Pacific in 1946 and 1948. See e.g., Report on Project Nutmeg (1950) DX-18 App.B; N. Smith, "First Revised Report of the Gabriel Project," (Nov. 1949), PX-721B; F. Reines, "Discussion of Radiological Hazards Associated with a Continental Test Site for Atomic Bombs," Los Alamos Scientific Laboratory, LAMS-1173 (Sept. 1950), PX-89/DX-13; R. Condit, et al., "An Estimate of the Relative Hazard of Beta- and Gamma-Radiation from Fission Products," NROL (Apr. 1949), PX-689/DX-591; see also the biological surveys of Alamagordo, New Mexico and Bikini Atoll, PX-352, 368, 678. The well-known handbook The Effects of Atomic Weapons, edited by J. O. Hirschfelder, Samuel Glasstone and others and prepared under the direction of the Los Alamos Scientific Laboratory, was published in June, 1950—six months before testing began in Nevada. See id. PX-690/DX-470. The Effects of Atomic Weapons devotes more than 150 pages to problems and remedies associated with "residual nuclear radiations and contamination," i.e., fallout. See id. PX-690/DX-470 at 248-400. The book discusses the nature of alpha, beta and gamma radiation, the contribution by fission products, neutron-induced activity and unspent ^{235}U or ^{239}Pu to fallout, the decay rate of fission products ($t^{-1.2}$), the relation between height of burst and fallout, the variability of fallout distribution, as well as monitoring instruments and techniques, and methods and procedures for decontamination. From the first atomic explosion it was known that tiny fallout particles would travel considerable distances: "radioactive dust produced in the atomic bomb ("Trinity") test at Alamagordo, New Mexico, on July 16, 1945, was detected by its presence in strawboard produce at Vincennes, Indiana on

August 6, 1945." Id. PX-690/DX-470 at 273, citing J. H. Webb, Phys. Rev. 76, 375 (1949).

While fallout from detonations in air "would not, in general, represent a real danger," the book notes an important exception:

> Special circumstances might, of course, arise, as indicated above, that would result in excessive contamination in certain localized regions. If there were a persistent wind in a particular direction, a larger proportion of activity would probably be found in downwind areas.

Id. PX-690/DX-470, at 274. Regarding treatment of materials contaminated with fallout, Glasstone and others advise:

> There are essentially three ways whereby the hazard associated with radioactive contamination may be minimized: first, to dispose completely of the material by deep burial in the ground or at sea; second, to keep it at a distance for a sufficient time to permit the radioactivity to decay to a reasonably safe level; and third, to attempt to remove the contaminant, that is, to decontaminate the material. These three procedures were used, in one way or another, in connection with radioactive contamination suffered by ships and their equipment after the Bikini "Baker" test.

Id. PX-690/DX-470, at 312. While decontamination measures are taken to minimize both external and internal exposure, The Effects of Atomic Weapons observes that contamination is largely a surface phenomenon except for liquid media, such as water. Id. at 321.

Therefore, decontamination often is accomplished through the cleaning of surfaces:

> The decontamination of personnel who have come into contact with radioactive material is, of course, a primary requirement. Normally, clothing will prevent access of the material to the skin.

> When contaminated, clothing should be removed and disposed of, by burial, for example, in such a manner as to prevent the spread of the radioactivity into uncontaminated areas, like the interior of buildings.
>
> Radioactive substances, especially beta emitters not accompanied by gamma radiation, when in close contact with the skin may represent a much greater hazard than would be indicated by an instrument held an inch or two away. Consequently, attention must be paid to cleansing any exposed surface of the body. A very fair degree of decontamination of the exposed skin can be achieved by vigorous rubbing with soap and water, paying particular attention to the hair, nails, skin folds, and areas surrounding body openings, and with due care to avoid abrasion. Certain synthetic detergents, of which many are now on the market, e.g., soapless household cleansers, have been found to be especially effective in this condition.

Id. PX-690/470, at 321-22 (emphasis added). The efficacy of simple scrubbing with soap and water as a decontamination technique was reiterated in the testimony of noted health physicist Dr. Karl Z. Morgan, see Tr. at 2835, 2840-42, 2846, as well as in contemporaneous documents authored by Gordon Dunning of the AEC Division of Biology and Medicine[105] and by James G. Terrill, Jr., Chief of the Radiological Health Program of the Public Health Service:

> The Public Health Service has operated under radsafe criteria in the Pacific and in Nevada which illustrate the type of emergency action which may be taken in the event of unexpectedly heavy fallout. . .
>
> Both of these criteria recommend remaining indoors or under cover during periods of fallout to avoid direct contact with falling or settling radioactive particles. If exposed to fallout personal decontamination is recommended including dusting and shaking-off or laundering clothes and bathing with particular attention being given to washing under the arms, the groin, face and hair. Covering of food and water to prevent ingestion of fallout particles is recommended.

"Technical Presentation for the Joint Committee on Atomic Energy Hearings on the Subject, The Nature of Radioactive Fallout and Its Effects on Man,. . . (May 28, 1957)" in Hearings, "The Nature of Radioactive Fallout and Its Effects on Man," Joint Comm. on Atomic Energy, 85th Cong., 1st Sess., (1957), Pt. 1, PX-831C, at 333.[106] When fallout monitors discovered contamination on their bodies, they showered. E.g., 2 Proceedings of the Offsite Monitors' Workshop, PX-288, at 74.

Experience with fallout in the 1946 and 1948 Pacific tests provided important data concerning the variability of beta-emitting fallout constituents in relation to the gamma-emitting radionuclides. Morgan reported monitoring beta/gamma ratios on Pacific target ships that were characteristically in the range of 3:1, with some readings running as high as 600:1. See Tr. at 2851. In a letter to fellow scientist Giacchino Failla dated January 24, 1951, Morgan describes his experiences:

> After eight years of experience dealing directly with problems of survey work and after making thousands of field surveys myself and many calculations of one sort or another, I have been convinced that there are certain practical problems of survey monitoring that are not necessarily obvious to one who thinks about the problem only from th standpoint of laboratory instruments or theoretical calculations. I was brought forcibly to this realization during the period following the underwater test at Bikini when I arrived there only to find that those in charge of monitoring were instructing personnel that the beta hazard would be directly proportional to the gamma hazard; that it would not be necessary to make beta ray evaluation. It was only after violent arguments that certain of the high officers arranged to assign me 12 men as a special survey team to cover various ships throughout the lagoon and measure the beta-gamma ratio. I was led to believe that this concession was to keep me quiet or enable me to prove myself that my views were wrong.
>
> Fortunately, I had taken with me about 20 instruments from our laboratory that were well suited to the measurement of beta-gamma ratio. The team of men assigned to me included a number of men who are now senior project leaders

and they did an excellent job collecting data indicating the beta-gamma ratio. Most places aboard ship the beta-gamma ratio ranged from 3 to 10. Some places it ran as high as 1,000. Many places the ratio was from 50 to 100. Wherever we found tar, paint, rust, rosin, wood, fabric, plankton, barnacles, etc., there was a selective absorption of the beta products as against the gamma emitting radioisotopes. We found places topside some of the ships where there was an indication of negligible gamma activity and yet several reps/hr of beta activity. Since it was customary for many of the men to sleep topside practically in the nude in the tropics when the ships were at anchor, it was probably fortunate that we made these measurements before the ships were boarded and before anyone received a serious beta burn.

I understand from Rose that when he was in the South Pacific he found it necessary to insist that the beta activity was not always proportional to the gamma. From Butenhoff's discussions in Washington, I gather that we are again faced with the same problem. If there is a fall-out of contamination due to rain over a populated area, past experience would cause us to anticipate that there would be many areas in which there would be considerable selective absorption of the beta emitters, and one might make dangerous assumptions about the radiation hazards if he is not equipped with instruments capable of qualitatively assessing the beta-gamma ratio.

* * * *

L. Taylor, Organization for Radiation Protection, supra DX-693 at 7-109, 7-110 (1980) (emphasis added). The Effect of Atomic Weapons describes in some detail the selective deposition of fission products on various surfaces and alerts the reader to the potential external beta radiation hazards not reflected by gamma radiation monitoring. Id. PX-690/DX-470 at 322 ff. Gordon M. Dunning in the "Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site," February 1955, reprinted in Hearings, "The Nature of Radioactive Fallout and Its Effects on Man," Joint Comm. on Atomic Energy, 85th

Cong., 1st Sess. (1957) PX-831C at 212, notes reports of beta/gamma ratios of 157:1 and 130:1, and engages in theoretical analysis assuming ratios of 100:1, 150:1 or 200:1. Id. at 219-22.

The significance of the beta radiation differential was summarized by Dr. Morgan at an AEC Symposium concerning "The Short-Term Biological Hazards of a Fallout Field" conducted in December, 1956:

> There are many factors that determine the type of fallout material from the detonation of a nuclear weapon, e.g., height of burst, distance from ground zero, type of weapon, weapon yield, meterological conditions, etc. Likewise it has been found that there may be factors (physical, chemical, and biological) which tend to fractionate and concentrate certain of the radionuclides. . . Under certain circumstances this fractionation may be of considerable importance because over-exposure to beta radiation can lead to serious erythema, burns, ulcers, and even death. Yet the most commonly used field survey equipment is designed to measure the absorbed dose from relatively hard gamma radiation and may give little or no response to beta radiation. Following the test of a thermonuclear weapon by the United States in the South Pacific in 1954, the more serious cases of radiation damage among the natives and operating personnel from the United States resulting from contact with the fallout materials were the consequence of exposure to beta radiation. It is sometimes stated that beta exposure is of little importance compared to the gamma dose from fallout material. . . I do not agree with this point of view and dare say some among the Marshallese, the Japanese fishermen, and the Americans who received painful and disfiguring beta burns as a consequence of exposure to fallout material in the South Pacific would not be inclined to underestimate the seriousness of exposure to beta radiation. In any case, the record should speak for itself—namely, the damage to man and animals (cattle, horses, deer, etc.) that has been observed from the fallout material from nuclear tests to date has resulted not from exposure to hard gamma radiation but from exposure to hard gamma radiation but from exposure to beta radiation. In

> assessing the hazard from fallout, therefore, one must be cautious not to overlook the seriousness of exposure to beta radiation, and one should not rely on a theoretical estimate of the isotopic distribution or one should not reach final conclusions regarding the radiation hazard unless measurements have been made of the absorbed dose from B and soft γ radiation.

K. Morgan, "Internal Dose from Short-Lived Radionuclides" in id. PX-641 at 149, 156-157 (emphasis added).[107]

The Effects of Atomic Weapons discusses important information about internal exposure resulting from inhalation or ingestion of fallout materials, and the radiosensitivity of lymph, bone marrow and other tissues. Id. PX-690/DX-470, at 350-54, 358-63, 396. "Some elements," the book states, "particularly iodine, strontium, barium, zirconium, and cerium, are strongly held in the body so that their consequences, when absorbed as radioisotopes, may be more serious than the amounts present would indicate. In addition, plutonium which has escaped fission, may represent an internal hazard although. . . the concentrations that are likely to be found after an atomic explosion are relatively small." Id. at 317-318. Cf. id. at 257 & n. 7; N. Smith, "Report of the Gabriel Project Study," Oak Ridge Nat'l Laboratory, May 1949, PX-679; id., (Nov. 12, 1949), PX-721B.[108]

The activities of groups such as the NCRP were directed to a significant extent towards the internal exposure problem. Dr. Karl Z. Morgan and others worked carefully over a number of years to formulate standards defining the maximum permissible internal concentration of the dozens of radionuclides produced by fission and other nuclear processes. See L. Taylor, Organization for Radiation Protection, supra, DX-693, pts. 7-8; K. Z. Morgan, "Permissible Quarterly Intakes of Radionuclides," in Handbook of Chemistry and Physics, pp. B-355-361 (64th ed. Weast 1983); ————————, "The Application of External and Internal Radiation Exposure Limits," 16 Am. Ind. Hyg. Assoc. Quarterly 307-323 (1955), PX-660. Prior experience with internal radium contamination alerted the experts in the field to the concentration of certain radionuclides in sensitive tissues years before testing began in Nevada. Concern over

strontium-90, an important bone-seeking fission product, resulted in the study known as Project Sunshine, which was conducted in the first years of Nevada testing. See e.g., "Project Sunshine: Worldwide Effects of Atomic Weapons," RAND Corp., August 1953 (amended)[109], PX-1027/DX-743.

The experience of the Government in detonating nuclear weapons in New Mexico, Japan and the Pacific taught important lessons about the effects of wind, weather, and geography on fallout distribution (including the concepts of "hotspots" and "rainouts"). The differences in fallout composition between low-altitude or surface shots and explosions at higher altitude were known:

> The relative importance of the sources of radioactive contamination following an air burst will depend on a variety of circumstances, for example, the nature of the terrain and the meteorological conditions. From a general point of view, however, the height of burst is perhaps of most significance, since this has a considerable influence on the more or less local contamination as well as on the fallout. . .

The Effects of Atomic Weapons, supra, PX-690/DX-470, at 268. Simply reading this handbook instructs one that

> Depending on the height of burst of the atomic bomb and on the nature of the terrain, high winds will occur in the immediate vicinity of the explosion. These, together with the air blast due to the shock wave, will cause various amounts of dirt and the particles from the earth's surface to be sucked up. . . . An ascending and expanding column of smoke is observed to form; it consists of water droplets, radioactive oxides of fission products, and more or less debris, largely determined by the height of the explosion. . . .
>
> * * * *
>
> [T]he fallout depends on debris of various kinds sucked up from the earth's surface after the atomic explosion. It is believed that for a sufficiently high burst relatively little extraneous material would be taken into the cloud, and the

> fallout would be negligible. This is in general agreement with experience from the atomic explosions over Japan. . . .

Id. PX-690/DX-470, at 32, 269. Of course, the authors note that even in dealing with fallout from a high-altitude burst "special meteorological conditions such as abnormal winds or perhaps rain clouds, might cause a large deposition of radioactive material in a particular area. . . " Id. The information in this unclassified handbook is stated in fairly general terms; the data on which it is based—the "top secret" details of observed patterns and effects —was also readily available to those working within the Government on designing and conducting continental nuclear tests. Basic theoretical models of fallout distribution were already in development.

Those responsible for radiation health and safety also had access to a considerable body of experience in radiation protection and personal and environmental monitoring. As Lauriston S. Taylor explained to the Joint Committee on Atomic Energy in 1957:

> A great deal of biological work was done by the Manhattan District Project in order to protect their own people, and this turned out to be very valuable and useful information with relation to maximum permissible exposure. Hearings, "The Nature of Radioactive Fallout and Its Effects on Man," Joint Comm. on Atomic Energy, 85th Cong., 1st Sess. at 786 (1957), PX-831C. Standard operating procedures at national radiation laboratories such as Argonne, Hanford, Oak Ridge and Los Alamos included strict precautions designed to minimize the exposure risk to workers as much as was reasonably practical. See e.g., J. Novak, ed., "Radiation Safety Guide," Arizona Nat'l Laboratory (June 1956), DX-687. At trial, Dr. Karl Z. Morgan, Director of Health Physics at the Oak Ridge National Laboratory for nearly 29 years, recounted the initiation of environmental contamination studies in 1945 and 1946, which traced the pathways of radioactive materials passed through the food chain, or through the air. Radiation workers were carefully and individually clothed, monitored and decontaminated using both estab-

lished methods and experimental techniques seeking improvement. They would shower, be checked and shower again to remove any residue. Tr. at 2841. Workers were not permitted to smoke, eat or drink in areas where radioactive contamination was likely to be present. In fact, the laboratory cafeteria was carefully swabbed with absorbent filter paper, which was then counted to detect contamination. Tr. at 2839-40.

The escape of curies, or even millicuries of radioactive material from Oak Ridge was carefully monitored, with fixed monitoring stations as far as 100 miles from the laboratory. Research was conducted into aerial monitoring techniques using small planes and specialized instruments. Health physics workers from Oak Ridge would often take instruments into homes in neighboring communities, looking for possible contamination. If radioactivity was found it was immediately cleaned up. Tr. at 2840.

Dr. Morgan described the type of instruments used, such as Geiger-Muller counters, and the simple combination devices that could be constructed to measure contamination of hands and feet, or that could detect internal thyroid exposure, or contamination over one's entire body. Tr. at 2843-45, 2856-58.

Dr. Morgan's testimony regarding safety measures at Oak Ridge have been supplemented by a series of written reports from the Health Physics Division of the Oak Ridge National Laboratory which were received as evidence.[110] Pointing to carefully kept exposure records for workers, the AEC's successor, The Nuclear Regulatory Commission (NRC), has proudly asserted that in most circumstances, radiation dosage was kept well below the maximum permissible levels as a result of these kinds of safety precautions. See e.g., BEIR-III Report (1980), DX-1025, at 49-57, table III-14.

One is relatively secure in concluding that in 1951, and more so in the years that followed, radiation protection methods were well known and stringently applied, particularly in the controlled environments of the national radiation laboratories. Relatively simple techniques involving easily used instruments and devices were

known—and routinely used—by those skilled in the field of radiation safety. Many civilian and military workers were trained in these methods by Dr. Morgan and others at Oak Ridge, as well as other laboratories. Among those receiving the earlier training and experience were men such as Oliver Placak and William S. Johnson, who shortly became involved in test activities in Nevada.

In summary, a good deal was known about radioactivity, and radiation, about atomic bombs, about fallout, and about real and potential effects on human health in 1951. This is not surprising at all. The study of nuclear sciences from 1930 onward has been intensive and unrelenting. The best efforts of many of our most skilled and creative scientists and researchers went into the exhaustive research leading to the atomic and hydrogen bombs, the controlled nuclear reactor, and the hundreds of other applications of radiation or radioactive materials. The quality of their work-product should not now be underestimated or ignored. Careful assumptions and inferences concerning radiation hazards were partly borne out by further data and experience in the 1950s or thereafter, but remain the subject of considerable study and discussion to this date. See e.g., Part IX, infra.

B. Design and Detonation of Nuclear Devices

There is no question that the original decision to establish a continental test site, the choice of the Nevada Test Site as the preferred location,[111] and the decision to conduct each series of atmospheric nuclear tests, whether in Nevada or in the Pacific, reflect the exercise of discretion at the policy-making level of the Government. These choices and decisions, therefore, are beyond the scope of our inquiry in this case pursuant to the Federal Tort Claims Act. See Part V, supra; 28 U.S.C. § 2680(a). Upon review of the edited documents and limited testimony in the record concerning the specific design of each series, and the individual test explosions within each series, this court is led to conclude that the "discretionary" nature of activities at the planning level extends to question of nuclear test design. Thus the decision to explode SIMON, a 43-kiloton device mounted on a 300 ft. tower, or CLIMAX, a 61-kiloton airdrop device, at NTS instead of the Pacific or underground, is beyond review, as would be the decision to

place HARRY, a 32-kiloton device tested in 1953, on a 300 ft. tower instead of a higher tower, or instead of being suspended from a balloon, or dropped from a plane. See e.g., "Radiological Safety Operation," Operation Upshot-Knothole (June 1953), PX-698, at 108, 124, 145.[112] When each explosion was actually detonated, and what was to be done as a consequence, were decisions made at the operational level. They were choices and judgments made by those charged with particular duties not discretionary in nature and not, therefore, immunized from review by the discretionary function exception to the Federal Tort Claims Act. See Part V, supra.

C. Timing of Nuclear Test Explosions at NTS

Whether for strictly technical reasons, or in the interest of public health and safety, it was within the power of the Test Site Director to delay and postpone the detonation of any nuclear device even in a matter of a few seconds before the explosion. A number of tests were in fact delayed for a number of reasons. See e.g., J. Reeves, "A Summary of Nuclear Detonations at the Nevada Proving Grounds" (1953), PX-73, at 1–4; Table of Test Events Delayed, PX-20/DX-987. Criteria were established on a continuing basis to assist test site personnel in evaluating the proposed timing of particular tests. For example, prior to the detonation of CLIMAX, the 61-kiloton test referred to above, the following criteria were promulgated:

> These criteria are intended to insure that no dangerous short range fallout shall occur outside the Proving Grounds and that the probability of any fallout outside the Proving Grounds shall be minimized.
>
> a. Desirable that winds aloft should be of reasonably low velocity.
>
> This restriction means that the cloud will still be over the Bombing and Gunnery Range, or contiguous areas of low population, when initial high-level fallout occurs, usually within three–four hours.

b. Desirable that some horizontal wind shear should exist aloft.

This is desirable since it causes horizontal diffusion of the cloud and consequent reduction in amount of fallout in any given location.

c. There should be no vertical shear or inversion such that blast is focused on Las Vegas.

*d. Populated areas which have received appreciable fallout on one shot shall not be subjected to fallout on subsequent shots.

e. Precipitation conditions within a thousand miles downwind should be avoided.

This criterion is intended to minimize the possibility of the cloud passing through precipitation originating at altitudes which will cause washout from the cloud.

f. Major populated areas such as Salt Lake City, etc., are given special consideration.

*Note: In the proposed eleventh shot of the UPSHOT-KNOTHOLE series this item would be emphasized, particularly with relation to communities such as Riverside Cabins, Bunkerville, and St. George's where our fallout activities have been most obvious thus far in the series.

"Meteorological Criteria for Nevada Proving Grounds," (June 2, 1953), DX-223. CLIMAX was exploded on June 4, 1953 after a three-day delay based both upon weather and technical problems. See PX-73, at 4. The resulting fallout was mapped on a path which avoided most nearby offsite communities; "[t]he upper portion of the cloud passed over St. George, Utah; but no radiation levels above background were detected on the surface of this location." "Radiological Safety Operation," Operation Upshot-Knothole (June 1953), PX-698/DX-194 at 144, 149 (map).

Avoidance of fallout reaching major population centers, such as Las Vegas, Salt Lake City, or Los Angeles was a constant matter of concern for Nevada Test Site personnel. Excluding these locations as acceptable "targets" for predicted fallout patterns limited the options available to NTS; only southern Utah, northern Arizona, southeastern and northern Nevada remain. Of the atmospheric tests conducted at NTS as of October 1958, at least 29 deposited significant, measured fallout in Utah, 16 in northern Arizona, and 18 in northern Nevada, while between 3 and 10 shots delivered fallout to Las Vegas and the California cities and towns. Between 1961 and 1970, 13 tests sent measurable fallout into Utah, while only 1 test touched California. See "Offsite Radiation Exposure Review Project," DX-1118, at pp. 52-53 (maps). In terms of sheer numbers, pelting St. George with the heavy fallout from shot HARRY in May of 1953 placed far fewer people at risk than scattering HARRY's hot ashes over Los Angeles or Fresno, it nevertheless put those thousands of persons in the St. George area at risk.

Review of the limited testimony see e.g., Tr. at 6260-6282 (testimony of Virgil Quinn) and documentary evidence relating directly to the question of timing, including the apparent use by NTS personnel of the available meteorological data in each test,[113] this court finds that the plaintiffs have not established by a preponderance of the evidence that the NTS Director and test site personnel negligently failed to exercise great care in light of the available scientific knowledge in the determinations made to detonate each device under then-existing meteorological conditions.

D. Offsite Monitoring of Radioactive Fallout Contamination

The evidence in the record clearly establishes that when it began continental testing of nuclear weapons in Nevada, the Government knew that radioactive fallout would be produced and that as a consequence the people living in off-site communities, the nation as a whole, and countries around the world would be exposed to some quantity of radiation in excess of that naturally occurring in the environment. The Project Gabriel study focused on the worldwide implications of fallout in 1949, paying particular attention to

risks of internal contamination by plutonium in fallout residues. See N. Smith, Jr., "Report of the Gabriel Project Study," (May 1949) PX-679; letter from Shields Warren, M.D. to Carroll Wilson, AEC, Nov. 23, 1949, PX-36. Assessment of the relative risks of fallout involved analysis of (1) external exposure to gamma and beta radiation; (2) internal exposure through ingestion or absorption of alpha, beta and gamma-emitting radionuclides; and (3) inhalation of fine particles of fallout debris, especially those containing high-energy alpha-emitters such as plutonium. Of particular importance were those isotopes which were known or believed to concentrate in sensitive organs and tissues or which would persist in the environment for extended periods of time. Retention of microgram quantities of plutonium-239,[114] strontium-90 or other isotopes with similar qualities was thought to pose a serious risk of cancer or leukemia, perhaps even more serious than that arising from radium ingestion.[115] The radioactive isotopes of iodine, particularly ^{131}I, were known to concentrate in the thyroid gland.

This court has reviewed at length the voluminous technical documents and reports prepared by Nevada Test Site personnel following each of the nine major series of atmospheric nuclear tests in Nevada. See 4 "Program Reports—Gross Weapons Measurements," Operation Ranger, WT-201 (1951), DX-90; 5 "Program Reports—Operational," Operation Ranger, WT-204 (1951), PX-741/DX-88; T. Shipman, "Radiological Safety—Operation Buster-Jangle," WT-425(EX), PX-361, 1023/DX-130; "Transport of Radioactive Debris from Operation Buster and Jangle, Project 7.1," WT-308(EX) (March 15, 1952), PX-739/DX-133; "Aerial Survey of Local Contaminated Terrain," Operation Jangle, WT-351 (1952), PX-350; K. Larson, "Field Observations and Preliminary Field Data Obtained by the U.C.L.A. Survey Group on Operation Jangle, November, 1951," UCLA-182 (Jan. 1952), PX-373; "Radioactive Debris from Operations Tumbler and Snapper—Observations Beyond 200 Miles from the Test Site," pt. 1, NYO-4505 (Jan. 12, 1953), PX-725; id., pt. 2, NYO-4512 (Feb. 25, 1953), PX-347; W. Johnson, et al., "Report of the Advisory Personnel to the Air-Sampling Program," Operation Tumbler-Snapper, WT-566 (June 1953), PX-362/DX-156; P. Gwynn, "Radiological Safety: Report to the Test Director," Operation Tumbler-Snapper, WT-588 (Del.)

(Dec. 1952), DX-152; J. Olafson, et al., "Preliminary Study of Off-Site Airborne Radioactive Materials, I. Fallout Originating from Snapper 6, 7 and 8. . . ," Operation Tumbler-Snapper, UCLA-243 (Feb. 1953), PX-742; "Report of Public Health Service Activities in the Off-Site Monitoring Program," Operation Upshot-Knothole (1953), PX-421/DX-195; T. Collison, "Radiological Safety Operation," Operation Upshot-Knothole, WT-817 (June 1953), PX-698/DX-194; C. Rainey, et al., "Distribution and Characteristics of Fall-out at Distances Greater Than 10 Miles from Ground Zero, March and April 1953," Operation Upshot-Knothole, WT-811 (Feb. 1954), PX-367/DX-200; NY00 Health & Safety Laboratory, "Radioactive Debris from Operations Upshot and Knothole," NY0-4552 (June 25, 1954), PX-283, 702/DX-201; R. List, "The Transport of Atomic Debris from Operation Upshot-Knothole," NY0-4602 (June 25, 1954), PX-1016; "Project Summaries of Civil Effects Tests," Operation Upshot (March 9, 1953), DX-173; G. Taplin, et al., "Evaluation of the Acute Inhalation Hazard from Radioactive Fall-Out Materials. . . ," Operation Teapot, WT-1172 (February 28, 1958), DX-359; E. Bouton, et al., "Fallout Studies," Operation Teapot, ITR-1119 (May 1955), PX-337; R. Lindberg, "Factors Influencing the Biological Fate and Persistence of Radioactive Fall-Out," Operation Teapot, WT-1177 (Jan. 1959), PX-701; R. Stetson, et al., "Distribution and Intensity of Fallout From the Underground Shot." Operation Teapot, WT-1154 (Mar. 14, 1958), DX-362; R. Mather, et al., "Gamma Radiation Field Above Fallout Contaminated Ground," Operation Teapot, WT-1225 (Oct. 28, 1959), DX-361; H. LeVine & R. Graveson, "Measurement of Off-Site Fall-Out by Automatic Monitoring Stations, Operation Teapot, WT-1186 (Dec. 1956), PX-8; L. Baurmash, et al., "Distribution and Characterization of Fall-Out and Airborne Activity from 10 to 160 Miles from Ground Zero, Spring 1955," Operation Teapot, WT-1178 (Sept. 1958), PX-344/DX-360; H. LeVine & R. Graveson, "Measurement of Beta and Gamma Ray Characteristics of Shot Debris and Fall-Out of Nuclear Weapons," Operation Teapot, ITR-1185 (Dec. 1955), PX-366; J. Sanders, et al., "Report of Off-Site Radiological Safety Activities," Operation Teapot (ca. 1955), PX-338/DX-354; "Radiological Safety Operations During Teapot," (June 14, 1955), DX-355; T. Collison, "Radiological Safety," Operation Teapot, WT-1166 (May 1955), PX-360/DX-357; ———, "Report of Off-Site Radiological Safety Activities," Project 56 (1955),

PX-48/DX-363; K. Larson, et al., "Distribution, Characteristics, and Biotic Availability of Fallout, Operation Plumbbob," WT-1488 (July 26, 1966), PX-341; O. Placak, et al., "Off-Site Radiological Safety Report," Operation Plumbbob, OTO-47-3 (1957), PX-339/DX-427; J. Shreve, "Summary Report, Test Group 57," ITR-1515(Del.) (April 1958), PX-724; O. Placak, et al., "Report on Off-Site Radiological Safety Activities," Project 57 (April 1957), PX-345/DX-364; id., Project 58 (Dec. 1957), DX-366; id., Project 58-A (1958), DX-365; id., Operation Hardtack, Phase II (1958), DX-447; "Final Report of Off-Site Surveillance for Operation Nougat," (Apr. 24, 1964), DX-458; "Interim Off-Site Report of the Des Moines Event," Operation Nougat (Aug. 10, 1962), PX-718/DX-460; O. Placak, "Final Off-Site Report of the Project Sedan Event," (Dec. 12, 1962), PX-628/DX-466.

This court has likewise reviewed the various radiation safety plans,[116] public information plans,[117] and related documents[118] pertinent to each of the test series, as well as the more general reports, summaries, statements and articles discussing fallout and radiation exposure. See e.g., H. Beck & P. Krey, "External Radiation Exposure of the Population of Utah from Nevada Weapons Tests," EML-401 (Jan. 1982), DX-1110; Dunning, "Radiation Exposures from Nuclear Tests at the Nevada Test Site," 1 Health Physics 255-267 (1958), PX-249; Schlein, "External Radiation Exposure to the Offsite Population from Nuclear Tests at the Nevada Test Site Between 1951 and 1970," 41 Health Physics 243-54 (1981), reprinted in Hearings, Sen. Comm. on Labor & Human Resources, 97th Congress, 1st Sess., at 197-208 (1981), PX-675, id., (in draft), DX-754; Federal Radiation Council, "Health Implications of Fallout from Nuclear Weapons Testing Through 1961," Rep. No. 3 (May 1962), DX-647; Memorandum, "Cumulative Estimated Dose in Milliroentgens For All Nevada Tests Through Operation Plumbbob," (1958), DX-763, 764; Memorandum to Alvin C. Graves, NTS, "Fallout Radiation Dose in the Nevada Test Site Region," (Oct. 26, 1956), DX-762; Thirteenth Semiannual Report of the Atomic Energy Commission, Sen. Doc. No. 3, 83d Cong., 1st Sess. (Jan. 1953), PX-206/DX-613; H. Hawthorne, ed., "Compilation of Local Fallout Data From Test Detonations 1945-1962 Extracted from DASA 1251, vol. 1, Continental U.S. Tests," (May 1979), PX-1021; Eisenbud & Harley, "Radioactive

Fallout in the United States," 121 Science 677-80 (May 13, 1955), PX-201/DX-593; Andrews, "Radioactive Fallout from Bomb Clouds," 122 Science 453-456 (Sept. 9, 1955), PX-323, 1054; Dunning, "Fallout From Nuclear Tests at the Nevada Test Site," prepared statement for congressional hearings, (May 1959), DX-756; C. Dunham, "Fallout from Nuclear Weapons Tests," in Advance in Biological and Medical Physics (ca. 1957), DX-749.

From the review of these and of other exhibits as well as significant oral testimony, from key participants in the test program,[119] the court has arrived at several important conclusions concerning the manner in which atmospheric tests and radiological safety programs were conducted. Those findings, conclusions and the evidence upon which they are founded is summarized in the sections that follow.

Review of the radiation safety plans and reports as well as more recent analyses of NTS monitoring data and the testimony of witnesses at trial, however, discloses an astounding fact: at no time during the period 1951 through 1962 did the off-site radiation safety program make any concerted effort to directly monitor and record internal contamination or dosage in off-site residents on a comprehensive person-specific basis. Widespread person-specific monitoring on a random sample basis did not take place until PLUMBBOB in 1957. Unlike the national laboratories such as Oak Ridge, where the quantities of material involved were a tiny fraction of those released at NTS, no routine urine, fecal or blood samples were taken from residents of local areas exposed to significant, measurable radioactive contamination. Not even in those circumstances where external exposures were estimated to meet or exceed the established safety guidelines, such as in St. George following the HARRY test in May, 1953, did the off-site rad-safe personnel make any effort to check possible internal contamination among residents by direct methods. No thyroid or whole-body counters were constructed for use in screening members of the community—especially children—who may have been exposed to more than was permissible even for radiation workers. In fact, in the aftermath of HARRY, the monitors decided not to take a number of milk samples in order to avoid arousing public concern. See e.g., Tr. at 4616, 4624-4656 (testimony of William S.

Johnson); W. Johnson, et al., "Monitoring of Cow's Milk for Fresh Fission Products Following an Atomic Detonation," LA-1597, at 3 (Oct. 1953), PX-363. Even if milk samples had been taken in methodical fashion, the analytical technique used to count radioactivity in the milk involved "dry-ashing" the milk at high temperature, driving off much of the radioactive iodine[120] and cesium-137[121] present in the sample. Concentration of those radionuclides was left to guesswork.[122] No mention is ever made of using blood counts as a method of monitoring in emergency situations, even though it was a technique in common use at radiation laboratories during that period. See generally, L. Taylor, Organization for Radiation Protection, supra, DX-693;[123] S. Glasstone, Sourcebook on Atomic Energy 601 (2d ed. 1957).

Arthur Wolff, Acting Chief of the Research Branch, Division of Radiological Health, U. S. Public Health Service wrote in 1962:

> We know the St. George and Cedar City areas have had several fallout incidents over the past years. I know of at least one incident in the Cedar City area (May 1953) when it can be calculated that the iodine levels in any milk produced in that area would have been comparable to those resulting from the Windscale incident. However, no one was looking at the internal exposure picture then, and the tacit assumption has been made that no internal hazards ever existed.

Letter to Chief, Technical Operations Branch, July 10, 1962, PX-442 (emphasis added).[124] Even the efforts actually made to indirectly estimate internal dose risks through monitoring of milk or food stuffs were haphazard at best.[125] No concern was shown for risks of ingestion of fallout beyond the time of crisis immediately following a detonation. Milk at Windscale (United Kingdom) was monitored for nearly two months following the release of radioactive iodine, krypton, xenon and traces of other nuclides by a reactor leak. In contrast, the radiation safety report for Operation UPSHOT/KNOTHOLE, the "dirtiest" of the Nevada test series, points with pride to the fact that

> The roll-up of the Rad-Safe Unit and preparation of the area for the interim period started directly after CLIMAX [61

> kt, June 4, 1953] and was completed by 12 June. All the personnel of the Off-Site Section departed by 9 June. . . .

barely five days after the last detonation. "Radiological Safety Operation" Operation Upshot-Knothole (June 1953), PX-698/DX-194 at 152. With no serious effort being made to monitor actual internal exposure, the "tacit assumption" of no internal hazard to off-site residents went essentially untested.

In a 1981 article, Bernard Schleien of the Food and Drug Administration reported with simple understatement that

> Internal exposure from inhalation and ingestion, and its contribution to the radiation exposure of the off-site population around the NTS has not been determined.

Schleien, "External Radiation Exposure to the Offsite Population from Nuclear Tests at the Nevada Test Site Between 1951 and 1970," 41 Health Physics 243, 253 (1981) reprinted in Hearings, "Radiation Exposure Compensation Act of 1981, "Comm. on Labor and Human Resources, 97th Cong., 1st Sess. (1981), PX-675, at 197, 207.

Internal dose assessment based upon inhalation of fallout particles involved a similar lack of direct monitoring. While some effort was made in the series to monitor the sizes of fallout particles this information is scattered at best. In the early series, direct human or animal data on inhalation is scarce, assumption having once more taken the place of careful measurement.

Those persons responsible for off-site radiation safety were aware that a number of persons in the Nevada/Utah/Arizona area surrounding St. George and Cedar City worked out-of-doors, and faced an increased risk of inhaling "hot" particles. Yet warnings to stay indoors were sporadic and lasted only a couple of hours. Even when fallout persisted in the area at levels measurably in excess of background, the assumption that inhalation of fallout involved a negligible risk of harm was not tested by direct examination until limited studies during Operation TEAPOT (1955) which were published 3 or 4 years later.[126] See also Appendix B, infra (complete

list of test operations, events, dates, and yield for NTS nuclear detonations.)

The inadequacy of data concerning internal exposure is underscored by the efforts of the Off-Site Radiation Exposure Review Project, which has been forced to construct sophisticated mathematical models and to make assumptions about critical dose factors all in an effort to reconstruct accurate dose data where little or none was actually measured at the time. See e.g., Tr. at 4803-4951 (testimony of Bruce W. Church); Tr. at 5661-5785 (testimony of Richard F. Smale); Tr. at 5785-5885 (testimony of F. Ward Whicker); Tr. at 5886-5967 (testimony of Dr. Lynn R. Anspaugh); Tr. at 6289-6338 (testimony of Dr. Robert D. Moseley, M.D.); Transcripts of Proceedings, Meetings of the Dose Assessment Advisory Group (DAAG), Dec. 1980 through May 1982, DX-1008 through 1019; see also DX-1118, with attachments. In a 1966 report issued by the UCLA civil effects test group, it is observed that "[s]tudies clearly indicated that accumulation of radionuclides by mammals cannot be assessed only on the basis of dose rate measurements of the gamma radiation field." K. Larson, et al., "Distribution Characteristics, and Biotic Availability of Fallout, Operation Plumbbob," WT-1488 (1966), PX-341, at 6. Yet as far as the mammals known as human beings are concerned, except for limited efforts at milk monitoring, external gamma dose rates are often the only direct exposure data available. In speaking of the need for direct monitoring of internal contamination in the off-site population, Dr. Karl Z. Morgan comments:

> Although we might have gotten zeroes, no indication of uptake of radioactive material, I always felt to have zeros on the record is a very worthwhile thing to have.

Tr. at 2825. With accurate, direct measurements of internal failout contamination, "then you are not guessing. You are not trying to convince yourself, well, this cloud could not have passed here. These people could not have gotten exposed." Id., Tr. at 2825.

It cannot be concluded that those responsible for off-site radiation safety exercised great care in light of the best of available scientific knowledge as far as monitoring of internal exposure re-

sulting from inhalation or ingestion of fallout material is concerned. Clearly, they did not. The negligence reflected in the monitoring program is highlighted by the fact that even now we have more direct data concerning the amount of strontium-90 deposited in the bones of the people of Nepal, Norway or Australia than we have concerning residents of St. George, Cedar City or Fredonia. See e.g., UNSCEAR Report (1977), PX-706/DX-605, ¶¶ 70-82 at 131-137. The notion that far greater releases of radioactive materials than at the other national laboratories somehow justifies far less monitoring than undertaken at those laboratories defies reason and logic, falling well beyond any notion of reasonable care under the circumstances.

The attention of the NTS off-site monitoring programs was focused almost exclusively on measurement of external gamma dosage received in the few hours immediately following each detonation. The report authored by Kermit Larson and others of the UCLA study group which participated in the monitoring of the PLUMBBOB series points out that:

> The assessment of biological hazards resulting from radioactive fallout produced by detonations of nuclear devices presents a problem that may be arbitrarily but incompletely divided into two phases. One phase is concerned with the acute or immediate hazards arising primarily from sources of radiation external to the biota and secondarily from the biotic accumulation of certain radionuclides classified as internal emitters. The other phase involves the chronic or long term hazards arising primarily from irradiation by internal emitters and secondarily from external radiation. These phases may be related to distance from ground zero or the time of deposition of fallout in the biosphere. Although the duration or effect at each phase is indefinite or incompletely known, such a division provides a focus of attention for a convenient experimental and observational approach to the assessment problems.

K. Larson, et al., "Distribution, Characteristics, and Biotic Availability of Fallout, Operation Plumbbob," WT-1488 (1966), PX-341, at 25 (emphasis added).

The off-site monitoring activities at NTS between 1951 and 1962 were overwhelmingly geared toward assessment of the first, acute phase of fallout hazard; prior to PLUMBBOB in 1957, the second phase was either largely disregarded or totally ignored. For example, second-phase long-term exposure problems were not monitored following the high-fallout tests of UPSHOT/KNOTHOLD; five days after the last explosion, there remained no one in the off-site organization to take any measurements. Everyone was gone. See "Radiological Safety Operation," Operation Upshot-Knothole, WT-817 (June 1953), PX-698, at 152. In this respect, UPSHOT/KNOTHOLE was the rule rather than an exception. Review of the radiation safety plans, reports and related documents for each of the test series reveals a consistent pattern of risk assessment that focuses almost entirely on acute exposure rates, risks and biological consequences. Each of the radiation safety plans, for example, included criteria for evaluating the need to implement evacuation procedures. Consistently, these criteria were attuned to the dosages that had been identified with acute symptoms of "radiation sickness." See Part IV, supra. Evacuation was recommended in situations where changes in blood cells could immediately be observed and "some injury" of an acute nature would result, (i.e at short-term dosages of 50+ rads). See e.g., The Effects of Atomic Weapons, supra, PX-690/DS-470, at 342. Though offsite exposures were not "permissible" beyond the 0.3 rad per week/ 3 rad in 10 weeks, or the 3.9 rad per year standards, the operational safety criteria often did not mandate decontamination procedures, e.g. washing of cars, food, etc., or special warnings unless the infinite external gamma exposure rate at a specific location exceeded 10 r. Monitoring instruments were often calibrated to the "hard" high-energy gamma rays emitted by cobalt-60 or similar isotopes and used to take quick readings of external gamma exposure rates. Little attention was directed to careful monitoring of lower-energy gamma rays, or to measurement of beta radiation or determination of beta/gamma ratios. On occasion, off-site monitors were specifically instructed to work with the metal beta shields on their instruments completely closed. See e.g., 1 Proceedings of the Off-Site Monitors Workshop, at 21 (1980), PX-297 (instructions for mobile monitoring teams, Operation Ranger: "Only gamma monitoring is to be done. Beta shields are to be kept closed.")[127] Monitoring of beta emitters was largely

left to the air-sampling activities of aerial monitoring or mechanical air-sampling stations. Actual measurement of off-site fallout exposure continued only for a matter of a few hours at best; particularly in the early series; the few off-site monitors, pressured by tight scheduling of detonations, would return quickly to the NTS and leave again to monitor the next test before data from the previous test could be properly analyzed. See 1 Proceedings at the Off-Site Monitors Workshop, 86-87, 125-126 (1980), PX-287.

Evolution of the early fallout data in light of acute dose concerns was apparently deemed adequate by test site personnel; little or no follow-up monitoring in downwind communities was attempted. Only as late as PLUMBBOB, the 1957 series, did the off-site monitoring program include film-badge monitoring on a geographically widespread, person-specific basis and even then only selected persons[128] in the many small communities.[129] See e.g., J. Reed, "Comparison of Fallout Doses from Nevada Tests (Revised)," Sandia Corp., (June 1960), PX-340/DX-766; cf. H. Knapp, "Gamma Ray Exposure Dose to Non-Urban Populations from the Surface Deposition of Nuclear Test Fallout," TID-16457 (July 1962), PX-717 for specific data on PLUMBBOB badge monitoring. While on-site personnel were routinely monitored using instruments, film badges and pocket dosimeters, and continuing individual records were kept, no personal radiation exposure "diaries" were kept for the thousands of people living in neighboring communities. The use of even the small number of badges involved in the PLUMBBOB monitoring pointed out the need for significantly greater effort in that direction. Statistical analysis of the PLUMBBOB badges was informative:

> Calculation shows that nearly eleven of Goldfield's 220 population received more than 3.9 roentgens. Revised Weather Bureau maps for this [Nevada] town show only an 1100-mr map dose, as compared to 1900-mr originally estimated; the new map value infers three people with 3.9 r exposure. The small six-badge sample average is about half the expected average and would extrapolate. . . to show that no one exceeded 3.9 roentgens. But again, with so small a data sample, mean and error statistics may be inaccurate; it therefore seems more reasonable to concede that several

> Goldfield people would have recorded more than 3.9 roentgens if they had carried badges.

J. Reed, "Comparison of Fallout Doses from Nevada Tests (Revised)," supra, PX-340/DX-766 at 25 (emphasis added). The same report concludes that while film badge readings "show that an average person receives less than half the radiation indicated by 'estimated' dose contours" on fallout maps,

> the large scatter of recorded dosages to people living within particular communities follows the logarithmic-normal distribution law, and in some of the larger towns, where "estimated" dose map contours show a much smaller average dose, a number of people probably received more than 3.9 r infinity dose. . . .
>
> Graphic solutions which have been presented should be used in future test operations to establish, from a fallout prediction, estimated wind-forecast errors, and population numbers, that no one will receive an excessive fallout radiation dose.

Id. PX-340/DX-766 at 26 (emphasis added). Film badges and pocket dosimeters were familiar items to radiation workers in 1951. The statistical analysis methods were neither novel nor peculiar. See also H. Knapp, supra, PX-717. Had even a few badges been used in RANGER (1951) or BUSTER/JANGLE (1951) the analysis could have been made available to rad-safe personnel in TUMBLER/SNAPPER (1952), UPSHOT/KNOTHOLE (1953), TEAPOT (1955), and PLUMBBOB itself. They simply were not used.[130]

Even in dealing with "hard" external gamma radiation, dose estimation for the off-site residents amounted at best to an educated guess. Hastily taken, surface gamma measurements were generalized into smooth isodose lines on a fallout map and then "adjusted" downward by a factor of 2 or more to account for assumptions made about the attenuating effects of housing materials, automobiles, clothing, topography, distance and other

factors. Writing about similar mitigating factors in water contamination, Arthur Gorman pointed out in 1949 that:

> Radioactive particles carried into the atmosphere by gaseous effluent from nuclear fission operation could contaminate the air we breathe, and on settling, with or without rainfalls, contaminate the solid and vegetation on which they deposit. . . . Here again, the elements of time and dilution, as well as fixation are factors of safety. But an alert responsible sanitary engineer should not accept these favorable influences as a substitute for determining the facts.

A. Gorman, "Some Public Health Problems in Nuclear Fission Operations," 39 Am. J. Pub. Health 443 (April 1949), PX-45, at 448 (emphasis added). One lesson learned from experience in the radiation laboratories in this country and elsewhere in the world, the lesson taught by men such as Karl Morgan and organizations such as the ICRP and the NCRP—in dealing with radiation doses above background levels is, simply, "There is no substitute for measurement." This was graphically demonstrated in early experience with beta and gamma radiation in the Pacific tests and by the discovery of "hot spots" in the fallout pattern resulting from the first test at Alamagordo in 1945 and the early tests at Nevada. See e.g., 1 Proceedings of the Off-Site Monitors Workshop, at 85, 158-60 (1980), PX-287.

Yet little or no attention was paid to total beta exposure or to the beta/gamma ratios found to be of importance in the early Pacific tests. The overall approach to beta-emitters reflected in the conduct of the NTS off-site rad-safe programs appears to have been: "Take care of external gammas and the betas will take care of themselves." Current estimates of beta exposure have much more to do with theoretical fission product ratios, fractionation models and current measurements retrospectively analyzed than with actual contemporaneous measurements of real fallout conditions in down-wind communities. Members of the Dose Assessment Advisory Group in evaluating the work of the Government's Off-Site Radiation Exposure Review Project continually express concern

about the large degree of assumption, uncertainty and potential error inherent in a dose estimation process so lacking in basic empirical measurements. Dr. F. Ward Whicker, leading designer of the theoretical pathway models used by ORERP to calculate internal exposure estimates, prefaces his work with cautious skepticism:

> Basically, I don't believe in models even though this is what we are working on unless they have been carefully validated against real data. Most of the parameter values were developed elsewhere under different conditions; there are all sorts of reasons why the model may not really simulate the real system that we are trying to simulate, and so the only way that I'll ever have any confidence in a model is to test it as thoroughly as you possibly can; so we put great emphasis on this. . . .

1 Proceedings, Dose Assessment Advisory Group, July 22, 1981, DX-1014, at 38-39; see Tr. at 5785-5885 (testimony of O. F. Ward Whicker). Another participant, Seymour Jablon of the National Academy of Sciences, stated:

> I find oppressive the number of assumed constants and guesses that go into some of this structure, and I think it is very important that there be some effort to do what I have heard called propagation of errors, i.e., to see just how much variation in your end result arises from credible variation in values of parameters or estimates of population values you have to grind into the formulas.

2 Id. July 23, 1981, DX-1015, at 185; see also Tr. at 5945-5963 (testimony of Dr. Lynn R. Anspaugh). Had the off-site monitoring program taken adequate measurements of beta exposure, beta/gamma ratios and perhaps even regular measurements of alpha activity in dust particles likely to be inhaled, the current estimation efforts would require fewer assumptions.

Person-specific monitoring and recordkeeping through use of film badges or dosimeters would have largely eliminated the guess-

work used both then and now to assess external radiation risks to the local community. Indeed, the scattering of badges used in PLUMBBOB disclosed important error in the estimation factors used to that point. In circumstances in which test site personnel have reason to predict that exposures may approach—or exceed—the 3.9 r standard, the scientific justification for monitoring workers directly, but not the people around them, especially children, defies the imagination.

Had the Government accurately monitored the individual exposures in off-site communities at the time of the tests, accurate estimation of actual dosage to individual persons could have been achieved. The need for particular precautions could have been evaluated with confidence. Had even the existing programs of surface measurement continued over a longer period, the second phase, or chronic hazard of radiation exposure could at least have been given minimum analysis. Months or weeks of monitoring, rather than days or hours of monitoring, were practical in other contemporaneous nuclear laboratory or accident situations. In southern Utah, northern Arizona and northeastern Nevada, however, measurable amounts of fallout contamination persisted for much longer periods of time than did the efforts of those charged with the duty of taking measurements.[131]

Careful review of the numerous relevant documents, reports and statement which are now a part of the record in this case compels this court to conclude that the monitoring activities conducted in the areas surrounding the Nevada Test Site in an effort to ascertain external doses of radiation were persistently negligent in philosophy and action. The monitoring program as carried out necessarily produced inadequate data from which to accurately evaluate either acute, short-term or chronic, long-term risks of adverse health effects, especially as related to children. Long-term exposures and risks, particularly those related to external beta and internal exposure, alpha, beta and gamma radiations, were never adequately measured or analyzed during the period of atmospheric testing. The inability of current dose estimation projects to make reasonably confident dose estimates based solely on the contemporaneous measurements by NTS neatly underscores the inadequacy of that data at that time as a basis for making those estimates at that time.[132]

Furthermore, the basic preparations for off-site monitoring were inadequate in terms of numbers and training of monitors as well as in resources, such as film badges, available to the effort. A review of the total numbers of monitoring personnel, film badges, meter readings, and other indices of activity reveals significant differences between test series. See DX-1118. For example, Operation PLUMBBOB employed a total of 198 monitors in the off-site program, while Operation UPSHOT/KNOTHOLE—conceded by the Government to be the series yielding heaviest contamination —employed a total of 37 monitors. Only TUMBLER/SNAPPER and HARDTACK II used fewer personnel, 26 and 25 respectively. Consequently, it is not surprising that the records of UPSHOT/KNOTHOLE include 5,644 survey meter records, while 30,156 PLUMBBOB meter records remain available. See Appendix C, DX-11181. The military personnel monitoring the TUMBLER/SNAPPER series reported 36 film badge records, while the 107 TEAPOT monitors reported 4,167 and the PLUMBBOB monitors reported 9,175. Appendix C, infra, DX-1118. Nothing in the record indicates any corresponding difference in potential fallout risk in the early series as compared to the later ones. While PLUMBBOB included more devices, UPSHOT/KNOTHOLE generated more fallout. See also Appendix B, infra.

The early test series were the subject of considerable internal review and criticism. In a "Preliminary Report on Buster-Jangle Fall-Out Program," dated December 15, 1951, PX-941, Harry Shulte reported that "[s]ignificant quantities of material were collected during the Buster Operation at distances ranging from 30 to 100 miles. The surface shot [SUGAR, 1.2 kt., Nov. 19, 1951] produced higher concentrations, and the underground shot [UNCLE, 1.2 kt, Nov. 25, 1951] still higher." While none of the measured concentrations had exceeded recommended guidelines, "the concentrations obtained even on Buster, were high enough that the possibility of exceeding such levels cannot be ruled out." Id. PX-941 at 5. Differences between airborne and ground concentrations of fallout from the SUGAR and UNCLE tests moved Shulte to remark that "[t]his indicates very definitely that the internal hazard from airborne activity cannot be assessed by surface activity measurements as obtained on survey instruments." Id.[133] Further, Shulte comments:

> It is difficult to see, at present, how the fallout program can be conducted on a much smaller scale and still yield useful results. One of the difficulties of interpreting data obtained at Buster or Ranger is in the uncertainty whether the location sampled was in or near the point of maximum concentration. For this reason, a large number of sampling stations must be employed.

Id. PX-941 at 6. While more fallout trays were used in TUMBLER/SNAPPER and UPSHOT/KNOTHOLE, see Appendix C, the number of monitors was significantly reduced. Reports from early series make reference to hasty preparations,[134] minimal training of personnel[135] and difficulties with communications at important moments. In the radiation safety report for the RANGER series, for example, Dr. Thomas Shipman wrote:

> The study of air-borne activities, with a consideration of individual particles, their sizes, and activities, obviously required equipment and an organization which could not be brought together in the time available. Studies on a very limited scale were carried out. . . it should be kept in mind that the levels found do not necessarily indicate the highest levels which might have been shown had the collecting station been placed in a more fortunate location. The successful collection of airborne material depends to a large measure on luck and on saturating the area with collecting stations.

5 Programs Reports—Operational." Operation Ranger, WT-204 (July 1952), PX-741, at 59.[136] A number of such problems are recounted by monitoring personnel themselves at the Off-Site Monitors Workshop conducted in 1980. See 1–3 Proceedings of the Off-Site Monitors Workshop, June 25, 26, 27, 1980, PX-287, 288, 289.

Monitoring techniques, personnel and collected data improved during later series,[137] and records became more quantitative than in earlier monitoring activities. While some person-specific film-badge monitoring was undertaken, much was still left to guesswork or rough "estimation." Ground readings were routinely used as a basis for dose assessment for most of the people in the offsite

communities, supplemented by the limited film badge and air sample data. In the off-site radiation safety report for the TEAPOT series, the importance of the film badge data is explained. Recalling that "infinite dose" and "effective biological dose" are mathematical extrapolations from a single reading by instruments, which will vary with the accuracy of the reading and the approximation of fallout time,

> Dosage determination by film badge measurements does not require a knowledge of fallout time. Film badges measure directly the actual dose present at a point during the time of exposure. If changes in radiation level occur during this time, such as the blowing away or covering up of radioactive material or the secondary deposition of radioactive material at a later time, these changes are reflected in the film badge readings but not in the infinite dose or EBD [effective biological dose] results.
>
> * * * *
>
> Film badges are a positive means of measurement of personnel exposure. Where film badges are worn by people, they measure the actual dose received as these people move about in their daily routine. As far as the individual's exposure is concerned, it is unnecessary to speculate as to his probable location to know his exposure, as is necessary when using monitoring measurements.

J. Sanders, O. Placak & M. Carter, "Report of Off-Site Radiological Safety Activities," Operation Teapot (1955) PX-338, at 122-123. The Report concludes that "[t]he large amount of data that can be obtained with relative ease and economy by film badge measurements indicates that these measurements should become a permanent part of off-site planning." Id. More extensive use was made of film badge monitoring in PLUMBBOB and to some extent in the several series that followed. See Appendix C, infra. In fact, the entire town of Alamo, Nevada (approx. 300 people) was badged during PLUMBBOB with an especially significant observed result:

> The most important feature of the study is the complete

willingness of people to cooperate in such an undertaking. Probable [sic] 99 per cent of the people were most cooperative and helpful. Only a dozen or so persons refused to wear film badges and of this number about half wore badges for several months and then apparently tired of the task. The more general attitude was to wear a badge as a personal protection measure and with the spirit of being useful or helpful in a program of interest and concern to the community and to the nation as a whole.

* * * *

As one would expect, some personnel badges were lost or damaged by such procedures as running the badge through a washing machine. However, the overall attrition rate was small and need not be considered as a real handicap to such a program.

O. Placak, et al., "Operation Plumbbob Off-Site Radiological Safety Report," (1957), PX-339/DX-427 at 103. Placak and others stated that the "major conclusion to be drawn from this study is the willingness of people to cooperate in such a program even when it required a small degree of personal inconvenience." Id. Unfortunately, that conclusion was not reached at the NTS Operational level until after the 1957 series; the most serious levels of fallout radiation exposure had already occurred.

Film badge data are not perfect. Badges may be damaged or lost. Film badges provide little information about beta exposure, less about beta/gamma ratios and almost nothing about internal exposure due to inhalation or ingestion of alpha-and-beta emitting radionuclides. Hair, hands, and shoes may collect more contamination than the shirt pocket where a badge may be clipped. Yet if one assumes, as the NTS radiation safety officers did, that external exposure to gamma radiation is the most important risk factor involved in fallout, then the film badge seems to be the easiest, cheapest and best way to accurately estimate individual external gamma dosage. Film badges were so used on test site personnel and off-site monitors beginning in Operation RANGER in 1951.

The notion of detecting radiation by the fogging of photographic film in a sealed package is as old as the work of Henri Becquerel in 1896. It is as old as the idea of radioactivity itself.

The failure of responsible persons at the operational level to utilize person-specific film badge monitoring of external radiation exposure of off-site residents plainly amounted to negligent conduct as a matter of fact, if not also as a matter of law, particularly in those circumstances in which it was anticipated that exposures might approach or exceed the maximum permissible dose standards which were purportedly being followed at those times.

This court has reviewed with considerable interest the struggle of current groups, such as the Off-Site Radiation Exposure Review Project (ORERP), and the Dose Assessment Advisory Group (DAAG), to analyze and estimate from what was and was not measured the relative risk to persons in the off-site communities at the time of atmospheric testing. See Transcript of Proceedings, Meetings of the Dose Assessment Advisory Group, 1980-1982, DX-1008 through 1019. The dependence of those activities upon assumptions, models and data from other times and places highlights both the inadequacy of the data regarding gamma exposure and the paucity of information concerning other exposure parameters. It further highlights the negligent failure of the off-site monitoring programs to gather sufficient information from which to speak with confidence about dose and relative risk—either then or now. At best, the monitoring effort was only able to give short-term guidance about the fallout hazard considered from the standpoint of acute radiation injury. Those who now seek such guidance as to long-term problems largely must look elsewhere for usable data, theories and models. That so much reconstruction is now required says a good deal about the thoroughness of the original effort.

E. Adequacy of Warnings & Information Given

Apart from actual monitoring, the off-site radiation safety organizations were charged with the continuing duty to inform and educate the off-site public about the nature and effects of radiation, atomic testing and fallout. From the beginning, public information was considered at the policy-making level to be an

important part of the continental testing program. The primary goals of the public information program were to achieve public understanding and acceptance of the need for continental nuclear weapons testing and

> "To help protect the public and its property by acting generally to obtain public cooperation in measures required to avoid or reduce hazard; specifically by: Informing the public of the nature and extent of any hazards and of precautions which may be taken; issuing warnings; and issuing reports, reassurances and interpretations."

"Abstract of Report," Comm. to Study Nevada Proving Grounds, February 1, 1954, PX-51/DX-1, at 48 (emphasis added). The evidence in the record now before this court demonstrates that the information provided to persons living in the off-site area surrounding the Nevada Test Site was woefully deficient in at least three respects: public education relating to the nature and extent of hazards—particularly the long-range risks associated with radiation exposure—was not adequate to inform off-site residents of the foreseeable risks arising from exposure to fallout in that area; nor was sufficient information provided to educate people as to precautionary measures that they could take to protect themselves, to minimize the degree of exposure to fallout contamination and the resulting degree of risk. Finally, warnings given at crucial times failed to provide enough information soon enough to be useful and effective.

The weaknesses of the public information program, like the shortcomings of the monitoring program seem in part to be traceable to a determination at the NTS operational level to modify the policy and approach to fallout radiation exposures in a fashion that ran directly contrary to sound principles of radiation protection. As early as Operation RANGER, individuals at the operational level drew distinctions between the radiation exposure standards applicable to workers at the Test Site and the radiation levels deemed acceptable in the off-site communities. While workers were to comply with the 0.3 r per week standard and were expected, for example, to obtain prior permission to acquire a one-time exposure greater than 0.6 r (up to 3.0 r at once), the approach to public safety was very different:

In considering the levels of radiation to which the general public might permissibly be exposed, we have tried to keep in mind the somewhat delicate public-relations aspect of the affair. It is felt that an uncompromising attempt to follow arbitrary levels could possibly result in more harm than good. The guiding principle, therefore, is the rather simple desire to assure ourselves that no one gets hurt. It is felt that figures must be used as general guides but that no drastic action which might disturb the public should be taken unless it is clearly felt that such action is essential to protect local residents from almost certain damage. It is assumed that any member of the general public may receive external exposure up to 25 r without danger. This is no greater exposure than many people receive in an only moderately complete X-ray examination. Exposures between 25 and 50 r certainly demand more consideration, and where there is danger of exposure within this range thought will be given to requesting people to stay in their houses, change clothes, take baths, etc. For areas where exposure above 50 r may occur, consideration must of necessity be given to evacuating personnel, but such a step would not be taken unless it is firmly regarded as essential.

It should be understood that the dosage levels which have been given will be the dosage calculated for a four-week period starting at shot time. It is obvious that the most intense exposure will be acquired within the first 12 or 24 hr. From this it would appear that, even were evacuation decided on, by the time a plan actually could be put into effect, the milk would have already been spilt. It should also be obvious that no exposure levels of the magnitude considered above are anticipated. Should hot spots be created, however, it is felt that we are prepared to meet the situation.

T. Shipman, "Report of Rad-Safe Group," in 5 "Program Reports—Operations," WT-204, Operation Ranger, at 69 (July 1952) PX-741/DX-88 (emphasis added). In effect, the operational rad-safe personnel had redetermined the "maximum permissible dose" to off-site residents to be something greater than 25-50 rads—for reasons having little or nothing to do with scientific evidence as to

long-term risks. The simplest of precautions, e.g., bathing, staying indoors, would be given the benefit of some "thought" if public exposures approached or exceeded this range. Yet according to the record in this case, at no time did those responsible for policy and planning at the Atomic Energy Commission, or the President, or the Congress, determine that the maximum permissible dose to members of the public from fallout exposure was anywhere near 25, 50, or more rads (r) or roentgens (R). To the contrary, for example, in a high-level meeting with the Military Liaison Committee, General Fields of the AEC stated that "the AEC operates on the principle that it has no right to subject the public to the radiation permitted for its own employees." AEC-MLC Minutes of 81st Conf., May 28, 1953, DX-566, at 2. The AEC Committee to Study the Nevada Proving Grounds elaborated upon this view:

> Off-Site exposure is, however, involuntary. The numbers of people involved may become large, and there is no limitation with respect to age or occupational relationship. The population includes pregnant women, young children, and many persons in the active child bearing age. The occupational exposure is not acceptable as a lifetime proposition for a general population. Representatives of the United States, United Kingdom, and Canada agreed. . . and the International Commission on Radiation Protection subsequently concurred, that the occupational exposure for atomic energy workers might be reduced by a factor which could be as large as 10 when applied to large populations.

"Abstract of Report," Comm. to Study the Nevada Proving Grounds, (Feb. 1, 1954), PX-51/DX-1, at 37. The entire thrust of radiation safety policy at the policy-making level in the testing program was directed toward keeping fallout exposure to the off-site public at or below the maximum limits for workers.[138] The 1954 AEC Committee Report specifically recommended that the off-site exposure standard "should be 3.9 r/yr, the figure being one of actual gamma exposure as measured by a reliable indicator of total body irradiation and corrected by a factor to reflect the effects of shielding and weathering." Id. PX-51/DX-1, at 38.

The Committee concurred in a finding that: "It may be

> stated with considerable certainty that no significant injury is going to result to any individual at these levels and the same thing would probably have to be said were there limits two or three times as high. At the same time there is no threshold to significant injury in this field and the legal position of the AEC deteriorates if there is deliberate departure from what could be generally considered a reasonable interpretation of accepted permissible limits.

Id. PX-51, at 38 (emphasis added). Nothing in that Report, or in other policy documents reviewed, deemed it acceptable to postpone warnings and precautions to protect the public until exposure exceeded 25–50 rads—the level at which observable acute biological injury or effects would occur.

While the safety criteria in the operations following RANGER expressed intent to comply with the 3.9 r in 13 week or per year standards, the schism between test personnel and off-site residents in terms of the rad-safe program's approach to risk and monitoring/and prevention techniques remained a factor throughout the subsequent series. Test personnel were commonly assigned film badges and dosimeters; residents were not. Test personnel were regularly directed to shower, bathe, change and launder clothing, decontaminate vehicles, buildings and work areas and to exercise care to avoid ingesting or inhaling fallout materials.

In UPSHOT/KNOTHOLE, specific contamination levels were established—for workers—to be checked using instruments. For example, "Skin readings should not be in excess of 1 mr/hr. Complete decontamination by bathing is to be attempted." T. Collison, "Radiological Safety Operation," Operation Upshot-Knothole, WT-817 (June 1953), PX-698/DX-194, at 18. Although the same or even stricter exposure standards were to be applied to the off-site population, no general direction was given to residents to shower or bathe carefully, change and launder clothing; except for brief efforts at washing vehicles at roadblocks, decontamination activities in the communities were minimal. This disparity ran contrary to the public-related obligations recognized by the Government.

According to the AEC Committee to Study the Nevada Proving Grounds in 1954, one major obligation of the continental testing operation was

> to operate as safely as possible in view of the nature of a national necessity for the undertaking, and to try constantly to reduce any public hazard. Public cooperation in reducing the hazard will be advanced by:
>
> Informing concerned publics of the hazards to be created and of preventive action the public should take;
>
> Warning people in advance of potentially hazardous situations, or of situations which may alarm them;
>
> Reporting after the fact not only with reassurances but also with details and interpretations, whether the situation created was actually dangerous or only disturbing.
>
> * * * *

"Abstract of Report," supra, PX-51/DX-1, at 18. The Committee in reviewing the relevant activities in the first four series observed that "[p]lanning did not, however, go very far into the job of assisting safety and of off-setting panic by education, warnings and reports."

> The need for such actions became obvious within the first series and they have progressively—but not comprehensively—been incorporated into operations. . . .Where they have not be incorporated fully—as with radiation—the lack has contributed to the repeated flareups of public concern. . . .
>
> Most of the public-related situations which have developed have been met adequately, but on an after-the-fact, stop-loss basis. Most of the public problems which would, or might, accompany planned future operations could have been anticipated, planned for in detail, and prepared for by advance action such as public education.

Id. PX-51/DX-1, at 20, 21. The Committee noted sardonically that "[i]t is clear that much of the public relations program, including public information, for each series has been well-tailored for the series which preceded it."

> For instance, education and information planning for the 1953 series [UPSHOT/KNOTHOLE] was on a basis of a maximum 3 r exposure to the nearby public, which had been approached in the 1952 series [TUMBLER-SNAPPER]. When exposure equalled and exceeded this figure, there was no firm basis for public explanation or for interpretation of the exposure.

Id. PX-51/DX-1, at 21 (emphasis added).

The 1954 Report was critical of a number of short-comings perceived in the first four series:

> With the exception of a single occasion when Groom Mine personnel were evacuated in advance, there has been no specific pre-shot or post-shot warning of probable fallout within the Site region, it having been considered on several occasions, but test management having felt that public education and understanding were not sufficiently advanced and that the panic potential was too great. Prior to one Jangle shot, evacuation buses were stationed in Caliente without public explanation and there was serious public concern.

Id. PX-51/DX-1, at 43 (emphasis added). The shortage of public information about fallout compounds itself: operational personnel decided that inadequate public education justified a failure to warn.[139]

> The nature of reporting has varied with circumstance and with location. During Ranger and Buster, test information announced NPG region readings, usually comparing them to chest X-ray or wrist watch exposure. Reports in the site region and nationally were primarily an assurance of no hazard. With Jangle and the tower shots of Tumbler-Snapper, local exposure levels were not usually announced but reassurances were issued; simultaneously [New York Operations Office] did release, upon inquiry, national fallout levels and reassurances. Prior to Upshot-Knothole, the 13th Semiannual Report tabulated fallout experience in the NPG region and

nationally. It was decided that each shot's fallout levels would be announced during Upshot-Knothold. This decision was abandoned when Lincoln Mine exposure following the second shot approached, in early interpretation, the maximum permissible level. Throughout the remainder of the series statements were confined to reassurances. In the 14th Semiannual Report, the evaluated exposure levels were recorded. Prior to Upshot-Knothole it was also determined that post-shot reports would be made to owners of livestock of nearby fallout levels, but this was not effected and it remained for owners to discover such exposure and report to the test organization. Two possible other areas of weakness in the NPG region reporting procedure is the delay—perhaps unavoidable—in determining where there is "significant" fallout, and the seeming lack of procedure for determining exposure of isolated individuals or groups. . . .

Id. PX-51/DX-1, at 44 (emphasis added). The 1954 Report identifies no less than eleven tests which "presented a significant hazard as to beta burns and as to whole body gamma exposure, of importance both to domestic animals and to people." Id. PX-51/DX-1, at 34. Those tests were:

Table 14.

date	series/ number	name	yield	type	Max. infinite gamma exposure *Roentgens
11/19/51	BJ-6	SUGAR	1.2 kt	Surface	27
11/29/51	BJ-7	UNCLE	1.2 kt	Crater	18
5/7/52	TS-5	EASY	12 kt	300 ft. tower	15
5/25/52	TS-6	FOX	11 kt	300 ft. tower	2
6/1/52	TS-7	GEORGE	15 kt	300 ft. tower	6
6/5/52	TS-8	HOW	14 kt	300 ft. tower	3
3/17/53	UK-1	ANNIE	16 kt	300 ft. tower	6
3/24/53	UK-2	NANCY	24 kt	300 ft. tower	5
4/18/53	UK-6	BADGER	23 kt	300 ft. tower	7
4/25/53	UK-7	SIMON	43 kt	300 ft. tower	15
5/19/53	UK-9	HARRY	32 kt	300 ft. tower	12.5

*Calculated from the exposure rates at the "hot spot" of highest detected readings.

Id. PX-51/DX-1, at 34; U.S. Rep't of Energy, Announced United States Nuclear Tests July 1945 through December 1979 (1980) PX-728, at 6-7; accord, id. July 1945 through December 1981 (1982) DX-1007; Appendix B, infra.[140] "None of the hot spots," the 1954 Report assures us, "hit on occupied communities, but the edges of the heavy fallout areas did in several instances," resulting in estimated exposures of several Roentgens in St. George, Hurricane, Bunkerville, Kanab, and Orderville, among others. The report lists only two occasions when the off-site residents were advised to remain indoors: NANCY (March 24, 1953) and HARRY (May 19, 1953). Id. PX-51/DX-1, at 34–35. According to the AEC Committee in 1954,

> The present situation is that a sufficient degree of public understanding and of public acceptance has not been achieved. The immediate operating reason is that the educational and informational effort of the AEC and associated public agencies have not been sufficiently successful. . . .
>
> Various contributing reasons are also discernable. They are generalized here from analysis of four test series and without reference at the moment to corrective action taken in 1953 [:]
>
> * * * *
>
> There has been either lack of understanding or a lack in clarity of statement in official and semi-official statements. . . .
>
> There has been a major lack of understanding—or of agreement with the official AEC belief—on the part of scientists now or formerly connected with the program. . . To the press and public these individuals speak authoritatively, particularly when official AEC explanation is not immediately available.
>
> Action taken with regard to informing, warning, reporting, and damage claims has not been equal to the problem. The full scope of action to protect, warn, and inform the public—requiring as they do extensive action and timely action in widely dispersed regions—may quite probably be beyond the

internal resources of the Commission. Other federal and state agencies have responsibilities in public health and protection.

Special groups who are public opinion leaders have not been adequately briefed. Reference includes civil defense, physicians, prospectors, state and local health officials, veterinarians, etc.

The public, which is expected to accept a certain degree of hazard, has not been adequately informed of the extent and nature of the hazard. . . A limited effort was made midway in the Upshot-Knothole and in a few instances since to approach such explanation on the basis of possible emergency exposure, exposures actually experienced, and what various levels mean.

There have been only limited efforts to educate the public in preventive actions. Within the Site region there has been reference to confinement indoors, evacuation, and bathing. There is no understanding of when and why emergency actions may be undertaken. . . .

Id. PX-51/DX-1, at 46-48 (emphasis added). Far from being the strident criers of alarmists, these criticisms were the views of important persons within the AEC itself. The problems summarized in the 1954 report are highlighted, for example, in the actual events in St. George, Utah, immediately following the explosion of HARRY. See Appendix B, infra.

HARRY was detonated at 5:05 A.M., on May 19, 1953, with fallout initially projected to follow a southeasterly path. Fallout with an intensity greater than 1000 mr per hour was measured on U.S. Highway 93 between Alamo and Glendale Junction, Nevada, in direct line with St. George, Utah. While fallout occurred over a wide sector, the heaviest amounts proceeded on to St. George. T. Collison, "Radiological Safety Operation," Operation Upshot/Knothole, WT-817 (June 1953), PX-698/DX-194, at 121, 128 (map). Frank Butrico, an off-site monitor assigned to St. George, was not made aware of the imminent approach of the HARRY fallout to St. George until it arrived and registered on his own instruments

beginning at 8:50 A.M. F. Butrico, "Report on Sequence of Events in St. George, Utah, following Shot Harry," (May 1953), PX-12. See also Excerpts from monitoring log, Shot Harry, PX-25, 938/ DX-196; "Discussions with Frank Butrico," Aug. 14, 1980, PX-290. By 9:15 to 9:30 A.M., in the center of St. George, Butrico's own instrument was reading off the scale, indicating exposure rates of greater than 350 mr per hour. Tr. at 843. Butrico double-checked his instrument, called William Johnson, a radiation safety official at NTS and reported the situation:

> Q: What did Mr. Johnson tell you to do at the time of that first telephone conversation?
>
> * * * *
>
> A: Check the instruments and be sure that at a different point some distance away, not too far away because we were keeping communications open, to take another reading. I reported back that the instrument was still off scale.
>
> Q: What did he tell you then?
>
> A: We will have to wait and let you know what to do next, if we do anything at all. . . .

Tr. at 844-845. At about 9:45 A.M., Butrico again called Johnson for instructions:

> Q: And did Mr. Johnson have a concrete plan for you to carry out at that point?
>
> A: No, other than what he had indicated that we were going to wash cars and we were going to try to get people indoors. To do this via some communication mechanism such as radio or television.
>
> Q: Did you know at that point, Mr. Butrico, whether there was a radio station in St. George or not?
>
> A: No.

Tr. at 846. Butrico then met with the Mayor of St. George, who suggested calling upon a radio station in Cedar City, Utah, for assistance. Tr. at 847. The Mayor, not Butrico, made arrangements for a radio announcement which was probably made at approximately 10:15 A.M. No other effort was made to reach towns to the east, such as Hurricane and Kanab; there were no monitors there to give warning. Tr. at 851-52. By 10:30 A.M. or so, most people in St. George had moved indoors.[141] By early afternoon civilian activities were returning to normal.

A: At about noon it was time to take some kind of a break, and communications were opened with the command post and Mercury [NTS]. And I had indicated that I was going back to the motel to wash up because I, very foolishly probably, was traveling around St. George without any head cover and I was getting some pretty high readings in my hair.

Q: Did you take readings on your own body?

A: Yes, indoors. So it was obvious that it was off me and not around me.

Q: Do you remember what those readings were?

A: Approximately what they were outside just for brief moments, but then they dropped considerably. And I'd indicated I was going to go ahead and shower as much as I could and get some shampoo and get some of that stuff out of my hair. . . .

Q: Who were you talking to?

A: This was to Mr. Johnson at Mercury [NTS].

Q: Did he tell you to decontaminate yourself?

A: Well, we were just having this kind of a conversation that I was pretty hot, and that I was going to do this, and this was a good idea. . . .

Tr. at 870-71. Butrico was further advised to purchase fresh clothing in St. George and discard his existing clothing, which he did. Tr. at 872.

Q: Did you take a shower?

A: Yes, a number of them that afternoon.

* * * *

Q: Did Mr. Johnson tell you that you should tell other people in St. George to decontaminate themselves?

A: No. That subject was not brought up.

Tr. at 872.

The experience of Frank Butrico in the aftermath of the HARRY test illustrates the unfortunate consequences of the inadequacy of the public education and information program, the warnings actually given on critical occasions, as well as the fundamental disparity between radiation protection measures for workers and for residents—a schism originating in the RANGER series and continuing throughout the atmospheric testing programs:

Q: But the [people of St. George] who were out of doors between 8:50 and 10:15 when the radio message came would have gotten the same exposures that you did?

A: Yes. That's a reasonable assumption.

Q: And they were never advised to shower and discard their clothes as you were?

A: That was never brought up, nor was it suggested.

Q: Well, did you think of exercising discretion on your own as a public health measure to give the kind of advice to people?

A: Well, in retrospect, yes, I should have concluded that if it was good enough for me, it would be good enough for the general populace of St. George. However, also, reflecting on events now, I would have to say that more than likely it would not have been a very practical thing to do, nor a very effective thing to do in a community the size of St. George. One would have to assume that as the announcement on taking cover was only partially successful, that so would the hearing of the announcement. . . of decontamination also not to be heard by many, nor if it was, whether some would even heed that. . . .

Tr. at 873-74 (testimony of F. Butrico). Of course, the effort of one monitor working alone in the fallout field following the ninth explosion in the fourth test series to adequately educate and inform an entire community would be futile indeed. Had sufficient information been provided to the off-site residents about fallout hazards, and about useful precautions such as bathing, showering, and laundering of clothing, the burden of adequate warning would have proven far less onerous. As the 1954 AEC Committee Report points out, however, the off-site public information program had proven deficient in each of these respects. By the time of HARRY in May, 1953, it was readily apparent to the Test Organization that detonation of a 32-kiloton fission device atop a 300-foot metal tower would probably yield heavy fallout exposure somewhere. The failure of the off-site safety programs to adequately prepare the local residents to deal with a serious fallout event only compounded the problem.

The shortcomings and failures of the off-site radiation safety programs in the first four series moved the AEC Committee to Study the Nevada Proving Grounds to make specific recommendations in its 1954 Report:

17. Safety Requirements

* * * *

Radiation Exposure. On-Site exposure guide will continue

to be 3.9r/13 wks. with any exceptions, Test Organization or military, subject to the concurrence of Test Management. Major deviations will be subject to prior AEC authorization.

Off-Site exposure guide will be 3.9r/yr. or whole body gamma ray exposure as adjusted for shielding and weathering. All pertinent planning and controls will be based on insuring against public exposure exceeding the guide and will have as a further objective keeping exposure below that level.

The hazards of beta burns to livestock grazing near NPG must be accepted, although warnings and reports should be freely utilized to help reduce owner's losses.

Interference with commerce, industry, and research must be accepted, although warnings and reports should be freely utilized.

18. Public Relations Requirements.

Public understanding is essential to the public's acceptance of the costs, the health and property hazards even though low, and the interferences and annoyances resulting from continental tests.

Public cooperation is essential in reducing human and property exposure to off-Site effects.

These essential goals will be advanced by prompt, frank and comprehensive warnings and reports: by extensive and intensive education and information as to hazard, reduction and avoidance of hazard, necessity, economies, program results, and happenings of continental tests.

* * * *

It is stressed that the requirement for public relations activity, while it may grow more intense as a series approaches, is one for a continuing program and public-related service. The basis for public understanding and cooperation must be built in-between series. The public attitude expressed in a

series may well be the result of impressions gained from a succession of positive actions or lacks over a long period.

Id., PX-51/DX-1, at 54-55 (emphasis added). In so finding, the Committee had far more in mind than simple reassurances:

Considerable public criticism and unsatisfied press questioning resulted from highway blocks for radiation monitoring, while no similar criticism has resulted from blocks for flash protection. Two factors perhaps favor the action on flash, one being that the vehicle occupants get to view the flash and the other being that the hazard is visible and easily comprehended. With respect to fallout, vehicle occupants and the press could not understand why traffic was long delayed, monitored, and many vehicles washed when simultaneously we were stating that the exposure was non-hazardous.

c. It is suggested that the following operational actions will advance public safety and public relations in the fallout field:

A definition and interpretation of the full nature of the radiation hazard (or exposure) which the publics in various geographic areas are asked to accept, or may experience in any degree of emergency. Equally frank discussion of the effects on fallout of varied yields, height of burst, and weather.

The most extensive possible program of education in the facts of hazard, the meaning of exposure, controls and emergency actions, etc., through all possible channels, including on-Site participants and observers, AEC and related personnel, opinion leaders such as doctors, health officials, news media, etc.

Expansion of the present Public Health Officer or project-related monitoring concept to arrange in each radiation-affected region for the relaying of advance warnings and of follow-up reports to local business, industry, and research.

Id. PX-51/DX-1, at 50 (emphasis added).

Pursuant, perhaps, to additional Committee suggestions, see id. at 60, the NTS radiation safety program made subsequent use of public lectures, films, distribution of small pamphlets and contacts with press, community leaders and medical professionals in an effort to both inform the off-site public in the vicinity of the Nevada Test Site along the lines indicated in the 1954 Report.

Careful review of two pamphlets widely distributed before and during the TEAPOT (1955), PLUMBBOB (1957) and later series discloses a greater quantity of relevant information than had ever been provided in prior series, yet the cautions and warnings given are greatly softened by broad reassurances of safety. Atomic Test Effects in the Nevada Test Site Region (1955), DX-1153, the first pamphlet, opens with a broad representation that

> No one inside Nevada Test Site has been injured as a result of the 31 test detonations. No one outside the test site in the nearby region of potential exposure has been hurt.

Id. DX-1153, at 2. A comforting statement—if true. The pamphlet makes similar reference to fallout experienced in prior series:

> The path of fallout is narrow at the test site and in the nearby region, widens to hundreds of miles as it moves on, and tends eventually to be distributed uniformly over the earth's surface. It does not constitute a serious hazard to any living thing outside the test site.
>
> * * * *
>
> As the AEC has reported, no person in the nearby region has been exposed to hazardous amounts of radiation, even from this heavier fallout and no crops or water supplies have been made hazardous to health.
>
> * * * *

Id. DX-1153, at 17, 18. Even the booklets "explicit" warning about the hazards of "beta burns" is carefully qualified:

If highly radioactive fall-out particles are deposited on or very near the surface of the skin, such as on clothes or hair, and stay there for an appreciable period of time, beta radiation can cause hair loss, skin discoloration and burns. Beta burns are similar to burns produced by heat, except that they appear only after one or two weeks and heal slowly and more imperfectly. Beta particles can barely penetrate the skin and produce no other damage to the body. The only beta burns recorded from Nevada tests have been on the skin of some cattle and horses grazing within a few miles of the firing area. At greater distances, there is very little likelihood of beta burns. However, simple precautionary measures may be taken to reduce exposure. These include thorough washing of exposed areas as soon as possible after fall-out has occurred, and other measures to remove the particles, such as brushing or changing clothes.

l. DX-1153, at 19 (emphasis added). As we have seen, Parts III & V, supra, the statement regarding beta particles is accurate only if ıternal exposure is entirely disregarded. Part IV supra. And when re the concededly "simple precautionary measures" to be taken? irst, one has already been told that there is "very little likeli-ood" of their being needed. But even so,

If you are in an area exposed to fall-out, you will be so advised by our radiation monitors. If there is any probability that exposure to fall-out will approach our very conservative exposure guides, you will be advised what to do. As has happened at St. George and Lincoln Mine, you might be advised to stay indoors for a few hours until the fall-out loses its strength. If you have been outdoors during the fall-out you might be advised to bathe, wash your hair, dust your clothes, shake off your shoes, etc. If the fall-out is across a highway, traffic might be halted temporarily.

l. DX-1153, at 22-23 (emphasis added). You might even be told to under or even discard your clothes, as was common practice ith test site personnel. The pamphlet's discussion is concluded ith a statement, which in the specific context is baffling:

> Your best action is not to be worried about fall-out. If you are in fall-out area, you will be advised. If our radiation monitors advise precautionary action, do what they say. Please bear in mind that it is extremely unlikely that there will be fall-out above the expected low levels on any occupied community. If you think that maybe you have been in fall-out, or if you have other questions, get in touch with our monitors or with the Test Organization. Your questions will be answered.

Id. DX-1153, at 23 (emphasis added). Besides running contrary to the established and sound principles of health physics and radiation protection followed at that time as well as since, the advice—in the context of the local communities which had already experienced fallout contamination at levels approaching or exceeding established standard for workers—the advice is patently absurd.

Nowhere does the pamphlet advise residents that exposure rates had approached or exceeded the standards, nor does the pamphlet give any hint that residents should initiate decontamination procedures on their own, when contamination may only be suspected. Nowhere does the pamphlet indicate how effective some simple measures like wearing a hat, showering, bathing, or laundering clothes can be, if done thoroughly. "When in doubt, wash everything" seems like advice far more consistent with minimizing exposures than the advice given, "when in doubt, call the monitors or the test site." The pamphlet doesn't even provide telephone numbers. Since the first hours of exposure were well known to be most crucial in terms of total external exposure, any suggestion causing delay in decontamination multiplies the potential dose received. Yet the text of Atomic Tests in the Nevada Test Site Region gives not a hint of that. Even the separate appendix section of the booklet (entitled "Guides to Understanding Fall-out") gives little additional information. The more "technical" appendix informs the reader that:

> Overexposure to any kind of nuclear radiation causes injury by damaging the tiny living cells of which our bodies are composed so that they cannot do their normal work in the body. The amount of overexposure to radiation determines

the amount of damage caused. We become ill from radiation only if too many cells are damaged or destroyed at one time, or are destroyed continuously in certain organs of the body over a long period of time.

Recovery of people injured by overexposure to radiation depends, as in the case of accidents, burns, or sickness, on the kind of injury and its severity. Many people who were severely injured by bomb radiation in Japan during World War II apparently made good recoveries. The important fact about radiation is that it takes quite a bit of overexposure to cause illness. Only when overexposures are very heavy is recovery problematical.

Id. DX-1153, at 34 (emphasis added). While "many" people who were seriously exposed to direct radiation at Hiroshima and Nagasaki "apparently made good recoveries," it was known well before 1955 that a number of Japanese atomic bomb survivors had already developed leukemia. The Atomic Bomb Casualty Commission was busily trying to keep track of those cases, as is its successor organization, The Radiation Effects Research Foundation, keeps track even now. The final word on that subject will not be spoken for years. See e.g., Comm. for the Comp. of Materials on Damage, etc., Hiroshima and Nagasaki: The Physical, Medical and Social Effects of the Atomic Bombings 186-332 (pap. ed. 1981).

Yet the booklet makes no mention at all of leukemia or cancer resulting from radiation exposure. Is cancer or leukemia a "problematical recovery" from a "very heavy exposure" that already caused acute radiation sickness? Is there any causal relationship at all? The reader is left guessing.

The significant thing about the "important fact" stated above is that in the long run it is simply wrong.

Even as to genetic changes, which were known to occur even at low doses of radiation, the pamphlet minimizes the apparent risks:

There has been considerable public discussion in recent

> months concerning the effect of radiation on the body's germ cells. Changes in the units of heredity in the germ cells, which eventually may appear as new or different characteristics in offspring, occur spontaneously under normal and natural conditions in all kinds of animals and plants. Normal radiation background is one factor in this process. Higher levels of exposure to radiation can affect the process. Radiation exposure to the population in the United States from fall-out generally has been less than the exposure received from natural background sources. On the basis of experiments and observations it appears that—over a number of generations—radiation from fall-out from Nevada tests would have no greater effect on the human heredity process in the United States than would natural radiation in those parts of the Nation where normal levels are high.

Id. DX-1153, at 20 (emphasis added). Of course, fallout generally distributed over the United States was significantly lower than fallout in the off-site communities of Nevada, Arizona, and Utah, which on a number of occasions proved significantly higher than background radiation. This distinction is not explained.

Finally, the booklet's concluding discussion of radiation protection standards carefully avoids reference to possible long-term effects of radiation exposure apart from the symptoms of acute radiation sickness:

> A dose of three-tenths roentgen per week has been accepted by both national and international groups of experts as the maximum dose rate which may be delivered to the whole body for an indefinite period of years without hazard. This does not mean that three-tenths roentgen is the largest exposure which may be incurred in one week without hazard. Occasional exposures well above this figure will have no detectable bodily effect.
>
> The lowest dose, received in a brief period, which will produce detectable effects in the body is about 25 r. and for many individuals will be 50 r. This 25 r.-50 r. range is generally considered an overexposure. Radiation sickness fol-

lows exposure somewhere in the 75 r.-100r. range, with nausea and vomiting occasionally found as low as 100 r. Serious illness, from which people will recover with proper attention — will result at the 200 r. level. Exposure to 400 r. in a brief period will probably kill 50 percent of all persons exposed.

Workers in the atomic energy program are governed by the three-tenths roentgen per week guide. Scientists and other participants in Nevada use a guide of 3.9 rad in 13 weeks, although they quite often are exposed to higher doses—because they must go into firing areas after a detonation.

Radiation exposure of the public is, however, different from that which atomic workers voluntarily accept. It is involuntary. The numbers of people involved may become large, and there is no discrimination as to age or occupational relationship. The population includes pregnant women, young children, and many persons in the active child bearing age. Exposure which the public should be asked to accept involuntarily should be—and is—lower than that atomic workers accept voluntarily.

For this reason, the Atomic Energy Commission has established a much lower guide for future Nevada test operations. It is essentially one-fourth the guide used for atomic test workers. The standard to be used will be 3.9 rad in 1 year, instead of a like total in 13 weeks.

Id. DX-1153, at 35-36. First, it is difficult to find any "national and international groups of experts" that endorsed the maximum permissible dose of 0.3 rad per week as a dose "without hazard"—i.e., a safe dose. Yet that is the impression left by the text, particularly when it ignores the serious concerns voiced by the NCRP and ICRP regarding long-term biological consequences of even low-dose exposures. If long-term hazards are ignored, the 0.3 rad standard looks extremely conservative indeed.[141A] Further, the booklet offers the comment concerning "pregnant women, young children, etc." without explanation of increased risk factors or any other basis. Consequently, parents are not alerted to the greater hazard faced by their younger children when exposed to radiation.

Finally, it is comforting to talk about a 1-year exposure standard for the public, though test series at NTS seldom continued longer than 13 weeks anyway. Test site personnel seemingly had few qualms about allowing the full 3.9 rad exposure to accrue to the off-site public during the few weeks of testing. See "Radiological Safety Criteria and Procedures for Protecting the Public During Weapons Testing at the Nevada Test Site" (Feb. 1955), DX-689, at 10 ("This total dose may result from a single exposure or a series of exposures"). While the 3.9 rad/year standard is more conservative than 3.9 rad/13 wks., how much more so, as a practical matter, is certainly debatable.

The apparent flaws and omissions in Atomic Test Effects in the Nevada Test Site Region are important not simply because they are so misleading; they merit close attention here because the booklet became such a key part of the off-site public information program:

> The news releases of the Joint Office of Test Information were widely used by monitors. However, the most valuable piece of educational material was the little yellow booklet, "Atomic Test Effects in the Nevada Test Site Region." Thousands of these were distributed through schools, post offices, motels, and by other means throughout southern Nevada and Utah, and in parts of Arizona and California. This was very well received. In fact, some people thought so highly of it that they requested copies to distribute on their own. Many of these booklets were picked up by tourists and were probably carried to all parts of the nation.

J. Sanders, et al., "Report of Off-Site Radiological Safety Activities," Operation Teapot (1955), PX-338, at 21. Clearly, many people were likely to have based their own evaluation of the fallout hazard on the soothing reassurances of the little yellow booklet, inaccurate as they were.

Two years later, immediately preceding the longer PLUMBBOB series, a revised pamphlet was issued and used in off-site communities. Entitled Atomic Tests in Nevada, the text of 59 pages was almost twice as long as its popular predecessor. Much of the earlier language is preserved in the second booklet, supplemented

with additional information describing the nuclear testing process. In reviewing the history of fallout exposure studies in prior test series, the booklet concludes:

> Simply stated, all such findings have confirmed that Nevada Test fallout has not caused illness or injured the health of anyone living near the test site.

Id. DX-1149, at 15 (emphasis in original). A National Academy of Sciences spokesman is quoted as saying, "The offsite exposure guides are regarded as safe, and there is no area that has exceeded the safe level." Id. With that assurance, the booklet lists "effective biological dose" estimates for a number of Utah, Nevada and Arizona communities, including some such as Kanab, Utah, which were not directly monitored prior to TEAPOT in 1955. Id. DX-1149 at 16-19. Atomic Tests in Nevada makes different comments concerning the 3.9 exposure standard:

> The 3.9 roentgens standard is not a level of exposure intended to be reached. The test organization will endeavor to keep fallout as near zero as possible. It should also be emphasized that the 3.9 roentgens is not a safety limit. Should a single exposure exceed this figure, it would not necessarily mean that the individuals concerned had been injured.

Id. DX-1149, at 28 (emphasis added). If not a safety limit, what is the standard? And simply because biological injury does not necessarily follow does not mean that injury is not a real possibility.

On the subject of warnings and precautions, Atomic Tests in Nevada in essence reiterates the views expressed earlier:

> If you are in an area exposed to fallout, you will be so advised by our radiation monitors who will explain just what is happening. If there is any probability that your exposure will approach our conservative guides you will be advised what to do. For example, at St. George and Lincoln Mine, residents were advised to stay indoors for a few hours until the fallout had ceased. If you were outdoors during the fallout, you might be advised to bathe, wash your hair, dust your

> clothes, brush your shoes, etc. If the fallout pattern is across a highway, traffic might be halted temporarily.

Id. DX-1149, at 33 (emphasis added). Once more, the curious advice is given:

> Your best action is not be worried about fallout. If you are in a fallout area, you will be advised. If your radiation monitors advise precautionary action, do what they say. Please bear in mind that it is extremely unlikely that there will be fallout on any occupied community greater than the past low levels. If you think that maybe you have been in fallout, or if you have other questions get in touch with our monitors or with the Nevada Test Organization.

Id. DX-1149, at 33-34 (emphasis added). This time, elsewhere in the booklet, two telephone numbers are provided. Id. at 43. Recalling that subsequent analysis of film badge data collected during PLUMBBOB indicated that a number of persons received exposures at or exceeding the established standard, perhaps the advice given was a little optimistic. See J. Reed, "Comparison of Fallout Doses from Nevada Tests (Revised)," Sandia Corp., SC-4414(RR) (June 1960), PX-340/DX-766. Once again, more detailed discussion of radiation effects was shunted to a separate appendix at the back of the booklet. The text is similar to the 1955 version:

> Nuclear radiation does different things to people depending upon what kind it is, upon the amount to which a person is exposed, and whether the whole body or only a part is exposed. Overexposure to any kind of nuclear radiation causes injury by damaging the tiny living cells of which our bodies are composed, so that they cannot do their normal work in the body. The amount of overexposure to radiation determines the amount of damage caused. We become ill from radiation only if too many cells are damaged or destroyed at one time, or are destroyed continuously in certain organs of the body over a long period of time.

Id. DX-1149, at 50-51. Review of basic health physics principles

discussed earlier, see Parts IV, VIII supra, would indicate that the word "exposure" far more accurately substitutes for "overexposure" as used in the quoted passages, particularly since "overexposure" is not specifically defined.

It seems useful at this point to contrast the basic information provided to residents by Atomic Tests in Nevada with that provided to workers at NTS. For example, Atomic Tests in Nevada next comments:

> The body can withstand considerably greater doses of radiation than that from normal background becasue the effects are repaired almost as rapidly as they are produced.

Id. DX-1149, at 51. Compare the treatment of the same topic in the "Basic Radiological Safety Training Manual," issued at the same time (February, 1957) to Employees of Reynolds Electrical and Engineering Co., Inc., an NTS contractor:

> Since there is no proof that living tissue is actually tolerant of ionizing radiation, even at background levels, the aim should always be to keep radiation exposures as small as possible.

Id. DX-700, at 8-4. The booklet states that

> High levels of radiation can produce effects such as blood and intestinal disorders, or delayed effects such as leukemia and cancer.

Atomic Tests in Nevada, DX-1149, at 51. Since fallout exposures are repeatedly characterized as low or very low, no connection would likely be inferred between fallout and risk of leukemia or cancer. The REECO Safety Manual, while also giving brief treatment to cancer and leukemia, states:

> There appears to be a very low threshold dose for changes in the blood picture caused by radiation. This may actually be zero dose (or no threshold) if a large population sample with known individual doses could be available for investiga-

tion. By special techniques, exposure of 0.3−0.5 r/month are detectable.

Following repeated small doses the white blood count is lowered (below 4000/mm^3 as compared to normal of about 7000/mm^3). . .

* * * *

Statistical studies have shown an increase of leukemia in individuals whose profesisonal work has exposed them to higher than acceptable permissible dose rates for a long period of time.

Id. DX-700, at p. 10-3. Workers reading their safety manual are informed that:

It is becoming established that shortening of life span is a general effect of whole body exposure to ionizing radiation. Experiments have also shown a similar reduction may be caused by irradiation of substantial portions of the body from ingestion of radioactive materials.

Id. DX-700, at 10-3. In Atomic Tests in Nevada, the wording is far more cautious:

There is some evidence both from animal experiments and mortality statistics of radiologists, some of whom may have received as much as 1,000 roentgens of x-ray exposure over a period of years, that radiation exposure shortens life expectancy. However, not very much is known about the quantitative relations between exposure to radiation and shortening of life.

Id. DX-1149, at 56. The earlier booklet, Atomic Test Effects in the Nevada Test Site Region, makes no mention at all of possible shortening of life-span.

In regard to internal exposure, the REECo Safety Manual advises that:

> Internally deposited radioactive material is considered more serious than external radiation because of the inability to facilitate complete removal from the organs. Radioactive particles will provide a source of radiation until removed or decayed; therefore, internal exposure can be controlled only be preventing the entry of radioactive materials into the body.

Id. DX-700, at 9-2. The Manual also provides a full page of discussion extracted from NCRP Handbook No. 52 concerning sources and variables affecting internal exposure from iodine, strontium, cesium, barium and other fission product radionuclides.[142] In Atomic Tests in Nevada, discussion of internal exposure is limited to a short treatment of strontium-90, with emphasis on the biological factors which lessen uptake of ^{90}Sr by humans. The public is assured that "[t]he amounts of strontium that have been found up to the present in milk and meat and animal products are detectable, but they are very low." Id. DX-1149, at 53. Of course, radioactive contamination of off-site milk was largely ignored before the TEAPOT series (1955), as were other food consumed in off-site communities. The earlier booklet makes no mention of internal exposure at all. Discussion in Atomic Tests in Nevada of possible genetic effects of radiation exposure was expanded from that in Atomic Test Effects in the Nevada Test Site Region, but the perspective taken remained the same. Once again, risk is evaluated in terms of risk across the entire United States, calculated from a theoretical figure: a 30-year gonadal dose of 0.1 roentgen to their whole U.S. population. Of course, earlier data in the booklet itself indicates that many off-site residents had already received 2, 4, 10, 30 or more times that amount to the whole bodies within a period of five years, not counting any internal exposure from ingested fallout material. The booklet's discussion of nationwide estimates, while interesting, was hardly relevant to the off-site situation.

Both the 1957 booklet and the REECo Manual indicate that genetic mutations occur at any level of radiation exposure. The safety manual—not the booklet—goes on to point out:

> Genetically speaking the effect is cumulative so that a

> given total dose may be received in a single exposure or distributed over any period during fertility. Also, considered population wise, the same mutation rates may be expected from a dose of 200 r in one individual or 2 r in 100 individuals. . . .

Id. DX-700, at 10-2.

Apart from disparities in more theoretical information, the information imparted to workers reflected a difference in philosophy and practice. The REECo Safety Manual, for example, emphasized taking of great personal care: "it is obvious that each individual must assume considerable personal responsibility for his own protection." Id. DX-700, at 9-1. The public information booklets on the other hand, offer little or no guidance to anyone in terms of self-motivated safety precautions. Total emphasis is placed on awaiting directions, if any from the monitors.[143] Unless otherwise informed, fallout was to be ignored.

Like its woefully inadequate predecessor, Atomic Tests in Nevada was widely distributed as part of the off-site safety program during PLUMBBOB:

> The green book, "Atomic Tests in Nevada," was used on an extensive scale. Approximately 30,000 copies of this book were distributed to groups, to individuals, and to various contacts for secondary distribution. Such contacts included state and national park personnel, service station operators, motel owners, post offices, stores, schools, etc.
>
> In response to written inquiries concerning nuclear weapons tests, fallout, and related subjects, many questions could be answered by sending a copy of "Atomic Tests in Nevada."
>
> Good public relations were aided by the widespread use of this book. It was well received in all quarters.

O. Placak, et al., "Off-Site Radiological Safety Report," Operation Plumbbob (1957), PX-339/DX-427, at 21. Good news usually is well received in all quarters. And being told that fallout is not a

health hazard and that one need do nothing unless told otherwise by a monitor had to be good news. Comforting as it was, however, it was not the kind of approach that was taken by test site personnel themselves, or by others better trained in principles of radiation protection. Neither pamphlet ever so much as suggests the simple idea that radiation exposure should be kept as low as practically possible because any degree of exposure to ionizing radiation may involve some degree of risk. Indeed, the pamphlets leave even the most studious layman with a strikingly different impression.

When shown in conjunction with films such as "Atomic Tests in Nevada," the reasons for total complacency about fallout must have seemed compelling. "Atomic Tests in Nevada," an AEC film widely exhibited in the off-site communities, meticulously avoids any hint of injury accruing from fallout exposure:

> Yes, the very nature of testing weapons for national defense requires we accept the possibility of some exposure to additional radiation. There is some potential risk, but this additional radiation has been kept far below harmful amounts in areas beyond a few miles outside the test site boundaries.

"Atomic Tests in Nevada," PX-913, Tr. at 280, 290. The events in St. George following HARRY in May 1953 are modestly reenacted in the film, with citizens taking shelter because, as the radio announcement intones, "There is no danger." Tr. at 281. A minor incongruity? The film much later explains,

> Actually, when the invisible cloud has passed, the total amount of radiation deposited on St. George was far from hazardous. Then you may ask: Why were the people asked to stay indoors? For a very simple reason. The Atomic Energy Commission doesn't take chances on safety. It is the AEC's policy to keep to a minimum any exposure of persons to radiation. This wide safety margin controls AEC's attitude toward radiation involved in any of its activities. So the citizens of St. George were asked to go indoors to avoid unnecessary exposure. The amount of radioactivity that fell on

> St. George was not dangerous. But the AEC felt the precaution to avoid exposure was good common sense. Such caution will continue to govern operations relative to the Nevada Test Site. With this rigid standard of safety, testing of atomic weapons must go on. Orderly, well-conceived testing must continue.

Id. PX-913, Tr. at 292-93 (emphasis added). To fully appreciate the artistry of the script one needs to recall two facts already discussed: (1) by UPSHOT/KNOTHOLE, the off-site safety organization was well aware that a person standing in the open as a cloud of fine fallout particles passed would receive a significant dose, although little would be deposited on the ground after it had passed;[144] and (2) minutes after fallout arrived in St. George that day, Frank Butrico's instruments peaked off the scale at 350+ milliroentgens—more exposure in an hour's time than atomic workers were normally permitted in an entire week. The high readings in St. George continued for the hour or more that passed before the key radio announcement was made. By that time the hair, skin and clothing of Frank Butrico had become seriously contaminated with fallout, as undoubtedly had the hair, skin and clothing of a number of residents of the off-site communities. Butrico showered repeatedly and changed clothing. The off-site safety organization, with its almost obsessive concern for safety (as implied by the film) neglected to advise the residents of those same simple precautions to avoid unnecessary exposure.

The booklets and the monitors frequently advised people to open windows or doors to avoid blast damage, and to avert eyes, wear dark sunglasses and put away the binoculars to avoid eye injuries due to the flash of the atomic explosion. Why similar, self-initiated safety precautions were seldom if ever suggested for reducing hazard to fallout defies scientific reason and common sense.

A number of precautions suggest themselves from knowledge and materials available at the time, precautions which were extremely practical, of little expense to the Government or the public, of a nature unlikely to arouse panic, yet relatively effective in

minimizing the potential for exposure. For example, employees of Reynolds Electrical and Engineering at NTS were instructed that:

> Common-sense precautions and good housekeeping techniques are a major deterent [sic] to contamination. Each worker should make a habit of cleanliness and thorough washing followed by monitoring before leaving the work areas. In almost every instance, personnel contamination results from a violation of established rules for using protective clothing.
>
> When it becomes necessary to decontaminate skin surface, a thorough washing with soap and water is generally effective for most contaminants. The contaminant is frequently loose material and can be removed by using black electrical tape, thus preventing the possible spread of material. . . Vacuuming is frequently effective in removing loose particulate from the scalp.

"Basic Radiological Safety Training Manual," REECo, supra, DX-700, at 14-3. The steps were simple: (1) locate skin contamination; (2) lift loose particles with sticky tape; and (3) "wash for two to three minutes with a good lather of mild pure soap in warm water. Rinse, dry and monitor." Id. [145] No special chemicals were required; in fact, organic solvents and special detergents might increase absorption of radionuclides into the skin. Just simple every-day soap in warm water worked well.

The use of washing to decontaminate people and surfaces soiled with fallout radioactivity was known to be effective as early as the 1946 atomic tests at Bikini. The standard handbook, The Effects of Atomic Weapons, instructed that "not only will soap and other detergents remove dirt, dust, grease, etc., which has become radioactively contaminated, but it is safe for most surfaces, nonhazardous, and does not call for particular expertise in its application." Id. PX-690/DX-470, ¶ 10.49 at 327-328.

For decontamination of clothing, the REECo Manual instructed workers that

Decontamination is performed as follows:

1. Three washes in a hot detergent solution. Tide is very effective for most contaminants. Rinse and dry.

2. Three washes in a warm 1% versene-detergent solution. Rinse thoroughly and dry.

Id. DX-700, at p. 14-6. While versene, a common laboratory chemical,[145] may not have been available at the corner drugstore, Tide was certainly to be found at the local market, and it is Tide, not the lab chemical, which is credited as "very effective for most contaminants." Id.

There is nothing frightening about being told to wash one's self with plenty of soap and water and one's clothing in a hot-water wash with Tide (or whatever) a time or two in order to minimize the chance of damaging exposure. To tell a farmer or rancher to wear a hat outdoors in the fields or on the range, and to thoroughly soap, scrub, shampoo and change clothes upon returning home, or when any suspicion of fallout contamination arises, seems almost too mundane. Yet this would be effective in reducing a good part of the total dose potentially to be received from actual fallout contamination.

The two booklets mention washing of people, but—strangely enough—not clothing, and not unless specifically instructed by NTS monitors. Why shouldn't people do it themselves, anytime there is any question of fallout?

Other simple precautions would have included thorough bathing, shampooing and fresh clothing for children playing outdoors following a nuclear test, or perhaps the suggested use of a simple cottonface mask by outdoor workers exposed to dust potentially contaminated with fallout; such masks have routinely been used for many years around insecticide, herbicide and fertilizer dust, as well as spray paint and other inhalation hazards, with no resulting public furor.

If it is explained that feeding cows on stored feed rather than on

open pasturage for a few days or weeks almost eliminates any fallout hazard in milk ultimately consumed by children, what dairy farmer could reasonably refuse? The 1957 booklet mentions strontium-90 in milk, yet says nothing of stored feed, or of diverting milk production from low-fallout pasturage into cheese-making, where processing delays would allow the traces of iodine-131 and other short-lived fission products to decay before ever reaching the market.[147] Where internal contamination is considered, using canned or powdered milk, eating canned food, or carefully scrubbing fresh garden produce are simple measures which could have been—but were not—suggested by these pamphlets, the films or the press statements.

Even with its weaknesses, the 1957 booklet was a material improvement over its predecessor, a consequence of the opinions of operational personnel that "we cannot again avoid realistic discussion of the hazard we are asking NTS region people to accept." Memorandum from K. Hertford to Gen. A. Starbird, Jan. 3, 1957, PX-213. See also, Memorandum, "Booklet for Next Nevada Test Series," R. Southwick to Gen.A. Starbird, Feb. 20, 1957, PX-218. In the five series preceding PLUMBBOB, however, realistic discussion had been avoided at the operational level in dealing with residents of the off-site communities. Operational negligence in the handling of the public information program effectively breached the legal duty to inform, to educate and to warn off-site residents of the increased hazards to which they were being exposed. Without more, the pamphlet Atomic Tests in Nevada fails of that purpose as well. With or without the printed booklets, the off-site radiation safety personnel were always free to supplement their program with any pertinent information that was not of a "classified" or secret nature. None of the information presented in the handbook The Effects of Atomic Weapons, published in 1950 as a standard reference source, was either secret or restricted. Information with that degree of detail was available to those responsible for off-site safety and education programs from several sources during the entire period of atmospheric testing. Unfortunately, it was seldom—if ever—used.

Considered as an evolving whole, the public education program in off-site communities was consistently heavy with confident re-

assurances. Important information concerning both risks and effective precautions was scarce at best and largely ineffective as a rule, at least as presented to the off-site public between 1951 and 1962. The failure of the long-term education program to fulfill its mission seriously undermined the effectiveness of the limited system of short-term announcements and warnings. An adequately informed community could take its own precautions to minimize exposure hazards upon receiving notice that a test was imminent, or had occurred, and that the inevitable fallout cloud was headed east, as it so often was.

Unfortunately, where simple precautions were concerned, the residents of the off-site region in Nevada, Utah and Arizona were left waiting for further instructions from those having better training and the best available information.[148] Although public information had improved considerably by the conclusion of atmospheric testing, it remained inadequate when measured by contemporaneous radiation protection philosophy and practices. The improvements in 1957, 1958 and 1962 only emphasize the serious failures to educate, inform and warn that characterize off-site safety activities in 1951, 1952, 1953 and 1955. While certainly the off-site residents were not—at least, not routinely—exposed to radiation in tens or hundreds of rads at a time, they were never fully and accurately informed of what it was they were exposed to, what it might entail in terms of long-term consequences, or how to keep the additional risk as low as was possible at that time. Consequently, many people were exposed to more radiation, and greater risk, than ever needed to be.

At the most fundamental level, the Government's failure to educate, to inform and to warn deprived those people living in the off-site communities of Utah, Nevada and Arizona of an opportunity —the opportunity to protect themselves, at least as far as was practical; the opportunity to evaluate the question of risk for themselves and their children; the opportunity to choose to leave the area of increased risk, or to choose voluntarily to stay. Radiation workers were permitted reasonably informed choices. Those who resided in areas where "occupational" exposure levels were so plainly foreseeable should have been afforded the same opportunity to choose.

That opportunity was wrongfully denied to the plaintiffs through the negligence of those who, on an operational level, failed to adequately educate, inform and warn.

This court is convinced that part of the program of public safety, the public information program was badly flawed, and that during the operation of that program, the information given to the off-site public as to the long-term biological consequences of exposure to ionizing radiation was woefully deficient—indeed, essentially non-existent. The off-site personnel failed to adequately inform persons at risk what the Government knew or could foresee concerning long-term biological consequences of radiation fallout exposure; failed to adequately instruct persons at hazard how to avoid or how to minimize such risk; failed to adequately, contemporaneously, and thoroughly measure and monitor such fallout so as to be able to inform persons at risk of the extent of the hazard faced by each; failed to explain the increased risks of radiation to children, infants and pregnant mothers; failed to adequately inform persons at risk of the dangers of eating or drinking food laced with radioactive fallout; failed to warn of the risk of feeding farm animals with forage dusted with radioactive fallout; failed to warn of the dangers of fallout entering into the food chain and the potential long-term biological risks involved in the eating of such food—particularly to children; and failed to adequately, intensively, and periodically advise persons at risk to do the simple things learned in prior Pacific experiments and laboratory practice, namely to stay indoors and under cover, shower, wash clothes, scrub and clean food, and if deeply worried, to evacuate or leave the area for other locations of less potential contamination.

The public pronouncements as given do not really warn and do not sufficiently educate. They reassure. They don't talk of potential long-term dangers. They talk of how effectively the program is being managed.

They do not "[inform] the public of the nature and extent of any hazards and of precautions which may be taken," the primary mission of such efforts according to the 1954 AEC Committee Report. See PX-51/DX-1, at 48. They demonstrate that responsible persons at the operational level of continential nuclear testing ne-

glected an important, basic idea: there is just nothing wrong with telling the American people the truth.

F. Summary

Both in monitoring and information activities, the off-site radiation safety program at the Nevada Test Site served largely to check the possibility of an immediate, acute exposure crisis resulting from nuclear fallout and to reassure the off-site residents that one would not occur. Long-term consequences of exposures below the acute symptom "threshold" were measured, analyzed and explained in terms of nationwide or worldwide populations placed at small risk, not in terms of local communities placed at greater risk. In both regards, monitoring and information, the employees of the defendant negligently and wrongfully breached their legal duty of care to plaintiffs as off-site residents placed at risk.

IX. THE QUESTION OF CAUSATION

Before any findings as to duty or negligent breach of duty may be applied to determine the question of liability, each plaintiff must show that he has suffered injury as a result of the defendant's conduct, at least in part. L. Green, et al., Cases on the Law of Torts 3 (2d ed. 1977).

> The plaintiff's starting point on the road to a tort recovery is to be able to pick the defendant out of the crowd; that is, to demonstrate factually that there is a reason why this particular person is the defendant. This is usually called the causation or factual causation issue. I find "factual connection" to be a more accurate term. Factual connection in the manner in which the term is used herein, carries no connotation of fault or of liability. It is the means of selecting a particular defendant on whom to focus the process of the legal system. It is the statement of what happened between plaintiff and defendant. Whether the factual connection between plaintiff's injury and defendant will lead to liability depends upon plaintiff successfully establishing the remainder of the issues that are relevant to the determination of liability.

Thode, "Tort Analysis: Duty-Risk vs. Proximate Cause and the Rational Allocation of Functions Between Judge and Jury," 1977 Utah L. Rev. 1, 2 (footnotes omitted).

The reason for this requirement was stated long ago by Professor Beale:

> Starting with a human act, we must next find a causal relation between the act and the harmful result for in our law—and, it is believed, in any civilized law—liability cannot be imputed to a man unless it is in some degree a result of his act.

Beale, "The Proximate Consequences of an Act, 33 Harv. L. Rev. 633, 637 (1920). As Dean Prosser explains, "Causation is a fact. It is a matter of what has in fact occurred." W. Prosser, Handbook on the Law of Torts 237 (4th ed. 1971).

In most cases, the factual connection between defendant's conduct and plaintiff's injury is not genuinely in dispute. Often, the cause-and-effect relationship is obvious: A's vehicle strikes B, injuring him; a bottle of A's product explodes, injuring B; water impounded on A's property flows onto B's land, causing immediate damage.

In this case, the factual connection singling out the defendant as the source of the plaintiffs' injuries and deaths is very much in genuine dispute. Determination of the cause-in-fact, or factual connection, issue is complicated by the nature of the injuries suffered (various forms of cancer and leukemia), the nature of the causation mechanism alleged (ionizing radiation from nuclear fallout, as opposed to ionizing radiation from other sources, or other carcinogenic mechanisms), the extraordinary time factors and other variables involved in tracing any causal relationship between the two.

At this point, there appears to be no question whether or not ionizing radiation causes cancer and leukemia. It does. Once more, however, it seems important to clarify what is meant by "cause" in relation to radiation and cancer:

> When we refer to radiation as a cause, we do not mean that it causes every case of cancer or leukemia. Indeed, the evidence we have indicating radiation in the causation of cancer and leukemia shows that not all cases of cancer are caused by radiation. Second, when we refer to radiation as a cause of cancer, we do not mean that every individual exposed to a certain amount of radiation will develop cancer. We simply mean that a population exposed to a certain dose of radiation will show a greater incidence of cancer than that same population would have shown in the absence of the added radiation.

J. Gofman, M.D., Radiation and Human Health 54-55 (1981), PX-1046.

The question of cause-in-fact is additionally complicated by the long delay, known often as the latency period, between the exposure to radiation and the observed cancer or leukemia. Assuming that cancer originates in a single cell, or a few cells, in a particular organ or tissue, it may take years before those cells multiply into the millions or billions that comprise a detectable tumor. As Dr. John Gofman explains, cancer is characterized by "the unregulated, uncontrolled proliferation of the descendants of a single changed cell. It is not that cancer cells divide more rapidly than normal cells; rather it is that they keep on dividing when there is no need for them." Radiation and Human Health, supra, at 60 (1981), PX-1046. Cf. BEIR-III Report (1980), DX-1025 at II-27.

The problem of the latency period is one factor distinguishing radiation/cancer causation questions from the cause-in-fact relationships found in most tort cases; normally "cause" is far more direct, immediate and observable, e.g., A fires a gun at B, seriously wounding him. The great length of time involved (e.g., A irradiates B, who develops a tumor 22 years later) allows the possible involvement of "intervening causes," sources of injury wholly apart from the defendant's activities, which obscure the factual connection between the plaintiff's injury and the defendant's purportedly wrongful conduct. The mere passage of time is sufficient to raise doubts about "cause" in the minds of a legal system accustomed to far more immediate chains of events.

The non-specific nature of the alleged injury further obscures the causal relationship between the defendant's conduct and the biological effects which are identified as consequences. Wounds and injuries from firearms, knives, heavy machinery, or other dangerous implements, for example, have particular qualities which are readily traced to source. Acute poisoning by specific toxic chemicals may be identified by specific symptoms or effects coinciding with the detected presence of the substance itself. Even acute radiation syndrome resulting from short-term exposure to 25 or more rads is fairly easily traced to source by blood counts and more externalized symptoms now identified to such exposure.

When the injury alleged, the biological consequence, is some form of cancer or leukemia, such specific clues as to cause, or source, are usually lacking:

> First, it must be emphasized and reemphasized that when a cancer is induced by ionizing radiation, the structural and functional features of the cancer cells, and the gross cancer itself, show nothing specific to ionizing radiation. Once established, a radiation-induced cancer cannot be distinguished from a cancer of the same organ arising from the unknown causes we so commonly lump together as "spontaneous." Spontaneous is an elegant term for describing our ignorance of the cause. The fact that radiation-induced cancers cannot be distinguished from other cancers itself indicates that there are profound common features among cancers, likely far more important than the differences.

J. Gofman, M.D., Radiation and Human Health, supra, at 59 (1981), PX-1046 (emphasis in original). Ionizing radiation—or other carcinogens—seem to add to the number of cancers already occurring in people, rather than producing new, distinct varieties of cancer. See id. PX-1046. The intrinsic nature of the alleged injury itself thus restricts the ability of the plaintiffs to demonstrate through evidence a direct cause-in-fact relationship between radiation from any source and their own cancers or leukemias. At least within the scope of our present knowledge, the injury is not specifically traceable to the asserted cause on an injury-by-injury basis.

This does not, however, end the inquiry. That the court cannot now peer into the damaged cells of a plaintiff to determine that the cancer or leukemia was radiation-induced does not mean (1) that the damage was not in fact caused by radiation; (2) that the radiation damage involved did not result from the defendant's conduct; or (3) that a satisfactory factual connection can never be established between plaintiff's injury and defendant's conduct for purposes of determining liability. Experience and the evidence in the record indicate that indeed it can.

> If plaintiff cannot establish a cause-in-fact connection between his injury and defendant's conduct that will support liability,. . . plaintiff should attempt to establish the most exclusive factual connection that he can between his injury and the defendant. This will normally involve some kind of a relationship between plaintiff and defendant. . . .

Thode, supra, 1977 Utah L. Rev. at 5 (footnote omitted). The more exclusive the factual connections that may be established by evidence, the stronger the rational basis for focusing the tools of legal analysis upon a specific defendant's conduct.

> For example, the fact that both plaintiff and defendant are members of the human race is one of the less exclusive connections possible and does nothing to explain why this defendant is before the court. That the defendant was in the area when plaintiff was injured establishes a more exclusive connection.

Id. 1977 Utah L. Rev. at 6. That the defendant was engaged in risk-creating conduct of a particular type, and plaintiff's injuries are consistent with the kind of harm that is predicted and observed when such risks are created, makes the factual connection seem even more exclusive—exclusive of other defendants, other connections, other "causes."

Whether any of these factual connections will lead to liability is, as Professor Thode reminds us, "an issue involving the scope of the legal system's protection afforded to plaintiff and is not an issue of factual causation." 1977 Utah L. Rev. at 6 (emphasis added).

Several relevant cases may be analyzed cogently in terms of factual connections rather than direct proof, tracing cause-in-fact. Summers v. Tice, 33 Cal. 2d 80, 199 P.2d 1 (1948), a California case touched upon in the first Allen opinion, relies upon factual connections in order to reach the question of liability. Plaintiff was struck in the eye by a pellet from a shotgun. Each of the two defendants had been present in the area near the plaintiff. Each had fired his shotgun in the direction of the plaintiff. The pellet was not uniquely traceable to one gun or the other. Notwithstanding that there was a physical cause-in-fact relationship between the injury and only one of the defendants, the trial court was permitted to reach the question of liability. In so holding, the California Supreme Court relied upon the earlier decision of the Mississippi Supreme Court in Oliver v. Miles, 144 Miss. 852, 110 So. 666, 50 A.L.R. 357 (1927). In Miles, two persons were hunting together; both of them shot at some partridges, and in doing so, shot across the highway. Plaintiff, traveling on the highway, was struck by pellets and injured. In holding for plaintiff, the court observed:

> We think that. . . each is liable for the resulting injury to the boy, although no one can say definitely who actually shot him. To hold otherwise would be to exonerate both from liability, although each was negligent, and the injury resulted from such negligence.

Id. 110 So. at 668 (emphasis added). In each case, "[t]he factual connection was established between plaintiff's injury and each defendant by a showing that each defendant was a person who had carelessly fired a shotgun in plaintiff's direction." Thode, supra, 1977 Utah L. Rev. at 6.

An earlier California decision, Ybarra v. Spangard, 25 Cal. 2d 486, 154 P.2d 687, 162 A.L.R. 1258 (1944), also seems to turn on reasonably exclusive factual connections between plaintiff's injury and the named defendant's conduct, rather than a direct showing of causation-in-fact by one defendant. In Ybarra, plaintiff, a patient in a hospital, awoke from a surgical operation with pain and paralysis in his right arm and shoulder which had not been present prior to the surgery. While expert testimony established that plaintiff's injury was of traumatic origin—some forceful "cause"—the direct cause-in-fact could not be more specifically determined.

The court held, however, that the plaintiff could maintain an action against any or all of the persons who had any connection with the operation even though he could not select the particular acts by the particular person which led to his disability.[149]

Other cases have also relied upon reasonably exclusive factual connections as a basis for reaching the liability issue. In Basko v. Sterling Drug, Inc., 416 F.2d 417 (2d Cir. 1969), plaintiff was blinded as a side effect of one or both of two drugs administered as treatment for a skin disease. Which drug "caused" the blindness could not be specifically identified. Nevertheless, the Court of Appeals for the Second Circuit, applying Connecticut law, held that "[i]n such a situation, either force can be said to be the cause in fact of the harm, despite the fact that the same harm would have resulted from either force acting alone. 2 Harper & Jones, [The Law of Torts § 20.2] at 1122-23." 416 F.2d at 429. The factual connection between plaintiff's injury and the defendant's conduct in issuing each of the two drugs was the administration of the drug to plaintiff and the injury to plaintiff consistent with observed side effects of the drug. Similarly, in Sindell v. Abbott Laboratories, 26 Cal. 3d 588, 607 P.2d 924, 163 Cal. Rptr. 132 (1980) plaintiff alleged injury due to cancer resulting from her mother's ingestion of diethylstilbesterol (DES) during pregnancy. The five defendant drug companies, manufacturers of DES at the times relevant to the plaintiff's injury, were held to be properly joined in the action even though plaintiff could not specifically identify the DES taken by her mother to any or all of the companies. That defendant A, for example, cannot be proven by evidence to be the actual source of the DES-caused injury to the plaintiff does not excuse A from the lawsuit. The Sindel court held that being a manufacturer of DES at the time when DES was dispensed to plaintiff's mother during pregnancy is a sufficiently exclusive factual connection to rationally justify reaching the question of legal liability of A for plaintiff's injury. Where another defendant could establish, for example, that it did not manufacture DES at that time, the factual connection vanished and the defendant was dismissed from the lawsuit.

In McAllister v. Workmen's Compensation Appeals Board, 69 Cal. 2d 408, 445 P.2d 313, 71 Cal. Rptr. 697 (1968), the California

Supreme Court reversed an administrative denial of a workman's compensation award to plaintiff, a fireman, who developed lung cancer after 32 years of firefighting and 42 years of smoking cigarettes. Even conceding that plaintiff's own cigarettes could have caused his cancer, the court found sufficient factual connection to keep the respondent employer in the case. The court's comments are instructive:

> We cannot doubt that the more smoke decedent inhaled—from whatever source—the greater the danger of his contracting lung cancer. His smoking increased that danger, just as did his employment. Given the present state of medical knowledge, we cannot say whether it was the employment or the cigarettes which "actually" caused the disease; we can only recognize that both contributed substantially to the likelihood of his contracting lung cancer. As we noted,. . . the decedent's employment need only be a "contributing cause" of his injury. And in Bethlehem Steel Co. v. Industrial Acc. Comm., supra, 21 Cal 2d 742, 744, 135 P.2d 153, 154 we pointed out a particular instance of this principle when we stated that it was enough that "the employee's risk of contracting the disease by virtue of his employment must be materially greater than that of the general public". . . .
>
> Although decedent's smoking may have been inadvisable, respondents offer no reason to believe that the likelihood of contracting lung cancer from the smoking was so great that the danger could not have been materially increased by exposure to the smoke produced by burning buildings.

Id. 445 P.2d at 318-319. The factual connection: plaintiff's injury was consistent with occupational exposure to greater-than-normal amounts of carcinogenic smoke.

In four other workmen's compensation cases similar to McAllister, an adequate factual connection has been established where evidence indicates that the occupational carcinogen probably contributed to the claimant's illness.

In Bolger v. Chris Anderson Roofing Co., 112 N. J. Super. 383,

271 A.2d 451 (Essex County Ct. 1970), a New Jersey court affirmed an administrative determination in favor of a claimant who was occupationally exposed to fumes from tar, pitch, asphalt and asbestos in "large and intense volume" over a period of years. Noting that the chemicals in question were known carcinogens, the court affirmed the compensation award upon a finding that the exposure had contributed to the injury, notwithstanding the fact that the claimant had also smoked cigarettes. Id., 271 A.2d at 457.

In Smith v. Humboldt Dye Works, Inc., 34 App. Div. 2d 1041, 312 N.Y.S.2d 612 (1970), a workmen's compensation award was affirmed on the basis of "substantial evidence" that the claimant's 25 years of exposure to known carcinogens in the dye compounds was factually connected to his papillary tumors of the bladder. Medical testimony was in direct conflict; statistical evidence was unclear. Yet a rational relationship between work and injury was identified as the basis for an award of compensation. See also Berman v. A. Werman & Sons, 14 App. Div. 2d 631, 218 N.Y.S. 2d 315 (1961); Casson v. A.C. Horn Co., 27 App. Div. 2d 966, 279 N.Y.S. 2d 244 (1967); Comment, "Judicial Attitudes Towards Legal and Scientific Proof of Cancer Causation," 3 Colum. J. Envtl. L. 344 (1977) and cases discussed therein.

In Besner v. Walter Kidde Nuclear Labs, 24 App. Div. 2d 1045, 265 N.Y.S. 2d 312, 313 (1965), another award was affirmed, this time in favor of a physicist who had contracted acute myeloblastic leukemia after working in a laboratory near cobalt-60 sources from which he received not more than 2,000 to 2,250 milliroentgens (mR) of gamma exposure. Relying in part upon presumptions available under the New York workmen's compensation statute, the appellate division affirmed, noting that the "record discloses that decedent was exposed to radiation for a substantial part of two periods and also at other times in various amounts. The testimony of the medical experts is emphatic that there is really no 'threshold' or 'safe' dosage of radiation because at the present stage of scientific knowledge it cannot be ascertained exactly what effects radiation has on the human body. It is also admitted that each individual reacts differently to exposure to radiation." 265 N.Y.S. 2d at 313. See O'Toole, "Radiation, Causation, and Compensation," 54 Geo. L. J. 751 (1966), and cases discussed therein.

In the most recent case, Krumback v. Dow Chemical Co., 676 P.2d 1215 (Colo. App. 1983), the Colorado Court of Appeals remanded a claim in which compensation had been denied following the exclusion of expert testimony by health physicists and others[150] which related the decedent's cancer of the colon to radiation exposures received while employed at the Rocky Flats nuclear weapons plant. On remand the State Industrial Commission reviewed the record and concluded that "jointly and severally the testimony presents competent and substantial evidence to support the referee's conclusions. . . that the claimant herein had sustained the burden of proof of injurious exposure of the decedent to the radiation alleged in the claim for benefits, and that said radiation was the proximate cause of the cancer of the colon which resulted in death." In re Leroy A. Krumback, W.C. No. 2-923-974, (Ind. Comm. Colo., dec. Apr. 19, 1984). The requisite burden of proof was satisfied by a showing of a "reasonable probability" that radiation exposure caused the decedent's cancer; the evidence indicated that Krumback had received an external dose of over 45 rems with additional exposure due to internal contamination by radioactive material. Id., 676 P.2d at 1217.

The labors of prior courts over the problem of factual connection between radiological insult and physiological injury are of assistance in resolving the similar questions presented here. Other cases lend aid as well.

A number of cases involving destruction of property by two or more fires or sources of fire, [151] or similar problems[152] may be cited wherein a factual connection establishing a rational relationship between plaintiff's injury and a defendant's conduct has been relied upon to reach questions of liability, even though a specific cause-in-fact relationship is not clearly identified. There are several cases in which the factual connection to plaintiff's injury is the defendant's failure to warn plaintiff or otherwise safeguard the plaintiff from risk or hazard. E.g., Haft v. Lone Palm Hotel, 3 Cal. 3d 756, 478 P.2d 465, 91 Cal. Rptr. 745 (1970) (father and son drowned in motel swimming pool: motel neither provided lifeguard nor warning that none was present); Reynolds v. Texas & Pac. Ry. Co., 37 La.Ann. 694 (1885) (plaintiff emerging from brightly lit train station onto unlit stairway at night, falls and is injured; negligence of railroad in not lighting stairway "multi-

plied" chance of accident); Kirincich v. Standard Dredging Co., 112 F.2d 163, 164-65 (3d Cir. 1940) (failure of crew to throw life preserver to drowning seaman); Berry v. Farmers Exchange, 156 Wash. 65, 286 P 46 (1930) (failure of building owners to provide fire escape not sufficient factual connection). See also Malone, "Ruminations on Cause-in-Fact," 9 Stan. L. Rev. 60, 77-81 (1956).

Sometimes the connection seems too improbable to the court to establish any basis for liability. See e.g., Kramer Service, Inc. v. Wilkins, 184 Mis. 483, 186 So. 625 (1939) ("no probability" that plaintiff's skin cancer was caused by cut resulting from falling glass). In other cases, it does not appear improbable at all. See e.g., Daly v. Bergstedt, 267 Minn. 244, 126 N.W.2d 242 (1964) (evidence of factual connection between injury from fall in defendant's store and subsequent tumor at site of bruise held sufficient to support verdict for plaintiff).

In some of the cases in which plaintiff has been injured, but has no means of identifying the specific cause-in-fact of the injury, the burden of proof has been placed upon the defendant to establish the factual details of the incident and show that defendant's conduct did not contribute to the victim's injury. Summers v. Tice is probably the best known example. Noting the inability of the plaintiff to identify which of the defendant's guns the injurious pellet came from, the court analyzed the problem as follows:

> When we consider the relative position of the parties and the results that would flow if plaintiff was required to pin the injury on one of the defendants only, a requirement that the burden of proof on that subject be shifted to defendants becomes manifest. They are both wrongdoers—both negligent toward plaintiff. They brought about a situation where the negligence of one of them injured the plaintiff, hence it should rest with them each to absolve himself if he can. The injured party has been placed by defendants in the unfair position of pointing to which defendant caused the harm. If one can escape the other may also and plaintiff is remediless. Ordinarily defendants are in a far better position to offer evidence to determine which one caused the injury. . . In a quite analogous situation this court held that a patient injured

> while unconscious on an operating table in a hospital could hold all or any of the persons who had any connection with the operation even though he could not select the particular acts by the particular person which led to his disability. Ybarra v. Spangard, 25 Cal. 2d 486, 154 P.2d 687, 162 A.L.R. 1258. [T]he effect of the decision is that plaintiff has made out a case when he has produced evidence which gives rise to an inference of negligence which was the proximate cause of the injury. It is up to defendants to explain the cause of injury. . . .

Summers v. Tice, 33 Cal. 2d 80, 199 P.2d 1, 4 (1948). This shift in burden of proof reflects a sound application of important legal policies to the practical problems of trying a lawsuit: where a strong factual connection exists between defendant's conduct and the plaintiff's injury, but selection of "actual" cause-in-fact from among several "causes" is problematical, those difficulties of proof are shifted to the tortfeasor, the wrongdoer, in order to do substantial justice between the parties.[153] If direct proof of actual cause is to fail, the ultimate burden of the injury should fall upon him who was negligent and who likely is in a better position to inform the court of the facts relating to cause.

In other cases discussed above, where plaintiff has produced evidence of factual connection sufficient to permit the drawing of a rational inference of causation—of some contribution by defendant's conduct to plaintiff's injury—it has been left to the defendant to prove otherwise. In Basko v. Sterling Drug Co., the U.S. Court of Appeals for the Second Circuit relied upon § 432(2) of the Restatement (Second) of Torts in holding that such an inference of causation may support a finding of liability. That section states:

> If two forces are actively operating, one because of the actor's negligence, the other not because of any misconduct on his part, and each of itself sufficient to bring about harm to another, the actor's negligence may be found to be a substantial factor in bringing it about.

If defendant's negligent conduct is found to be a "substantial

factor," it may in Restatement parlance be judged to be the "legal cause" of plaintiff's injury, i.e., defendant could be held liable based upon determination of the legal issues relating to liability (scope of duty, negligence, etc.). "The reason for imposing liability in such a situation," the court explains,

> is that the "defendant has committed a wrong and this has been a cause of the injury; further, such negligent conduct will be more effectively deterred by imposing liability than by giving the wrongdoer a windfall in cases where an all-sufficient innocent cause happens to concur with his wrong in producing the harm." 2 Harper and James, [The Law of Torts] supra at 1123. Similarly, in Navigazione Libera T.S.A. v. Newtown Creek Towing Co., 98 F.2d 694, 697 (2d Cir. 1938), Judge Learned Hand stated that "the single tortfeasor cannot be allowed to escape through the meshes of a logical net. He is a wrongdoer; let him unravel the casuistries resulting from his wrong." See also Malone, Ruminations on Cause-in-Fact, 9 Stan. L. Rev. 60, 88-94 (1956).

Id. 416 F.2d at 429. Implicitly the Basko opinion shifts the burden to defendant to produce evidence refuting causation if he is to escape liability once plaintiff has established a "substantial" factual connection between defendant's conduct and her own injuries.[154] The principle expressed in Restatement (Second) of Torts § 432(2) "applies not only when the second force which is operating. . . is generated by the negligent conduct of a third person, but also when it is generated by an innocent act of a third person or when its origin is unknown." Restatement (Second) of Torts § 432 comment b (1965). Thus a defendant may be held liable for negligent conduct with factual connections to plaintiff's injuries even where other concurrent forces of human, "natural" or unknown origin have similar connections.[155] Whether he is held liable, of course, is a question governed by distinct ethical, legal and public policy considerations. See Thode, "Tort Analysis: Duty-Risk Proximate Cause and the Rational Allocation of Functions Between Judge and Jury," 1977 Utah L. Rev. 1; Green, "Duties, Risks, Causation Doctrines," 41 Tex. L. Rev. 42 (1962).

The case of Haft v. Lone Palm Hotel, highlights an additional reason for assigning to the tortfeasor the burden of extricating himself from a tangle of causal forces. The defendant hotel's failure to maintain a lifeguard at its swimming pool did not merely aggravate the risks which took effect in the drowning of plaintiff's decedents; it also deprived the parties and the court of a potentially important witness on the subject of cause-in-fact: the lifeguard himself.

> Indeed, in some respects the instant action presents a stronger case for shifting the burden of proof to defendants than Summers, because the present defendants are in a sense more "culpably" responsible for the uncertainty of proof than were the hunters in Summers. Although the difficulty in proof in Summers was attributible to the coincidence of the defendant's actions, each hunter was negligent, not because he shot simultaneously with the other defendant, but only because he shot in direction of the plaintiff. . . . In the instant case on the other hand, the absence of definite evidence on causation is a direct and foreseeable result of the defendants' negligent failure to provide a lifeguard. Defendants may thus more appropriately be designated at "fault" for the factual deficiencies that are present.

478 P.2d at 476 (emphasis in original). Likewise, the Government's negligent failure to adequately monitor and record the actual external and internal radiation exposures of off-site residents on a person-specific basis has yielded many glaring deficiencies in the evidentiary record as it relates directly to the question of causation. The current multi-million dollar effort to reconstruct the radiation dosages received by plaintiffs or their decedents is constantly hampered by the failure of the off-site radiation safety personnel to gather whole categories of exposure data at the time that the exposures actually took place. Furthermore, had Government personnel provided adequate warnings of risk and information as to precautions minimizing the amount of exposure, a materially different picture as to appropriate inferences about factual connection and cause-in-fact might now be presented. Accurate monitoring of persons largely was not under-

taken; adequate warnings and information were almost entirely omitted from the operational radiation safety activities. A strong additional reason for shifting the burden of proof on the cause-in-fact question is thus readily apparent from the record.

This is not to say that this court presumes a causal relationship from the Government's negligence. To the contrary, as Dean Leon Green explains, "it will be noticed in these cases that the factual details of the immediate environment out of which the case arose must be shown with considerable particularity. Causal relation will not be presumed from the fact of injury or from a showing defendant has violated his duty." Yet so long as the evidence will support an inference that defendant's conduct contributed to the victim's injury, even though other inferences can be drawn that it did not, or that his injury was due to other causes, "it is for the finder of fact"—this court—"to draw the most appropriate inference using the court's own best judgment, experience and common sense in light of all the circumstances." Green, "The Causal Relation Issue in Negligence Law," 60 Mich. L. Rev. 543, 560 (1962) (footnotes omitted). This is true even in cases when it may be extremely difficult to establish a factual connection, where "the parties may have to rely almost wholly on scientific proof, i.e., the opinions of experts, and they may differ widely in their opinions." 60 Mich. L. Rev. at 561 (footnote omitted).

A useful analogy may perhaps be drawn from some of the currently proposed schemes for compensating long-term injuries to health allegedly caused by exposure to toxic chemicals and chemical wastes. The causation problems facing many toxic waste plaintiffs are strikingly similar to those facing plaintiffs alleging nuclear fallout injuries in this and other cases. Consider, for example, the problem of the "indeterminate plaintiff":

> We may know, for example, that a group of people has a specific type of cancer and that some of them contracted that cancer from exposure to the defendant's waste, but we do not know which individuals of that group were affected by the waste. The character of toxic waste injuries causes this uncertainty. We know what causes a broken leg or a black eye and can decide liability based on whether or not those causes

> were controlled by the defendant, but we do not know the mechanics of causation of cancers and nervous disorders. We are still at the elementary stage of knowing simply that they can be caused entirely or in part by exposures to certain substances; we cannot tie the exposures more precisely to the injuries.

Note, "The Inapplicability of Traditional Tort Analysis to Environmental Risks: The Example of Toxic Waste Pollution Victim Compensation," 35 Stan. L. Rev. 575, 582 (1983) [hereinafter cited Note, "Inapplicability of Traditional Tort Analysis"] (emphasis in original); Delgado, "Beyond Sindell: Relaxation of Cause-in-Fact Rules for Indeterminate Plaintiffs," 70 Cal. L. Rev. 881, 881-83 (1982). As the Note explains, "a toxic tort plaintiff typically can show only a 'causal linkage' between the toxic substance to which he was exposed and his type of disease or affliction." Like exposure to ionizing radiation, "most toxic tort injuries are of indeterminate causation. The etiology of the disease is unclear and the disease may occur in the absence of the suspect toxic contaminant." Id. 35 Stan. L. Rev at 583 & n. 31 (footnotes omitted). The concept of "causal linkage," coined by Professor Calabresi, refers to an empirically based belief that the act or activity in question will, if repeated in the future, increase the likelihood that the injury under consideration will also occur, see Calabresi, "Concerning Cause and the Law of Torts: An Essay for Harry Kalven, Jr.," 43 U. Chi. L. Rev. 69, 72 (1975)—a concept perhaps comprising one type of "factual connection" as developed earlier in this Part.[156]

Several recent legislative proposals make an effort to accommodate these practical complexities. Under three bills introduced in Congress in 1979,[157] persons claiming toxic waste injuries need only establish a "sufficient" relationship between the toxic contaminant, the injury, the geographical proximity and temporal extent of exposure. Negligence or other "fault" was not required to be proven before compensation would be paid. See Note, "Inapplicability of Traditional Tort Analysis," supra, 35 Stan. L. Rev. at 589. A bill[158] introduced in the United States Senate in 1980 provided that once a claimant made a prima facie showing of causal connection, the burden of producing evidence shifted to

defendant to demonstrate that exposure to its toxic chemicals was an insignificant contribution to claimant's injuries. Establishing a prima facie case required a showing that

> (1) the claimant had been exposed to a hazardous substance released by the defendant; (2) the exposure was in sufficient concentration and of sufficient duration to create a "reasonable likelihood" that it caused or contributed to the claimant's injury; and (3) there is a "reasonable likelihood" that exposure to that substance causes or contributes to the type of injury sustained by the claimant. . . .The defendant could rebut this showing only by demonstrating by a preponderance of the evidence that the contributing causes to the disease were apportionable and that its contribution was insignificant. . . .

35 Stan. L. Rev. at 590 n. 57 (citations omitted). While these specific proposals were not enacted, Congress did require a formal study of the toxic chemical injury problem,[159] which in 1982 made recommendations for a compensation scheme similar to the 1980 Senate bill. See Injuries and Damages from Hazardous Wastes—Analysis and Improvement of Legal Remedies: Report to Congress in Compliance with Section 301(e) of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (P.L. 96-510), pt. 1 at 206-219 (comm. print 1982).

Each of these proposals relies upon proof by the claimant of a series of factual connections which establish a rational, reasonably exclusive relationship between defendant's conduct in releasing lethally hazardous chemicals into the environment and each claimant's asserted injury. At least as to the cause-in-fact issue, such approaches are wholly consistent with the tort law analysis expressed in this Part.[160] Each of the prior cases analyzed has dealt to some extent with the problem of indeterminate causation. In each case, the court has applied common-law principles to fashion a remedial process that fairly compensates plaintiff's injuries while relieving the defendant of the burden of those harms which defendant can reasonably prove were not in fact a consequence of his risk-creating, negligent conduct.

A remedial framework can certainly be fashioned to meet the circumstances and requirements of the parties and issues now before this court in this action. To that end, this court now holds as follows:

Where a defendant who negligently creates a radiological hazard which puts an identifiable population group at increased risk, and a member of that group at risk develops a biological condition which is consistent with having been caused by the hazard to which he has been negligently subjected, such consistency having been demonstrated by substantial, appropriate, persuasive and connecting factors, a fact finder may reasonably conclude that the hazard caused the condition absent persuasive proof to the contrary offered by the defendant.

In this case, such factors shall include, among others: (1) the probability that plaintiff was exposed to ionizing radiation due to nuclear fallout from atmospheric testing at the Nevada Test Site at rates in excess of natural background radiation; (2) that plaintiff's injury is of a type consistent with those known to be caused by exposure to radiation; and (3) that plaintiff resided in geographical proximity to the Nevada Test Site for some time between 1951 and 1962. Other factual connections may include but are not limited to such things as time and extent of exposure to fallout, radiation sensitivity factors such as age or special sensitivities of the afflicted organ or tissue, retroactive internal or external dose estimation by current researchers, a latency period consistent with a radiation etiology, or an observed statistical incidence of the alleged injury greater than the expected incidence in the same population.

The Restatement (Second) of Torts offers some guidance for determining whether defendant's conduct amounts to a "substantial factor":

> The following considerations are in themselves or in combination with one another important in determining whether the actor's conduct is a substantial factor in bringing about harm to another:

(a) the number of other factors which contribute in producing the harm and the extent of the effect which they have in producing it;

(b) whether the actor's conduct has created a force or series of forces which are in continuous and active operation up to the time of the harm, or has created a situation harmless unless acted upon by other forces for which the actor is not responsible;

(c) lapse of time.

Id. § 433 (1965). One consideration is easily resolved; exposure to ionizing radiation from nuclear fallout cannot fairly be described as "a situation harmless unless acted upon by other forces." See also id. §§ 440-452. Others are more difficult:

> Experience has shown that where a great length of time has elapsed between the author's negligence and harm to another, a great number of contributing factors may have operated, many of which may be difficult or impossible of actual proof . . . . However where it is evident that the influence of the actor's negligence is still a substantial factor, mere lapse of time, no matter how long, is not sufficient to prevent it from being the legal cause of the other's harm.

Id. § 433, comment f. Implicit in the finding of "substantial factor" based upon relevant considerations is the exercise of sound judgment in light of the evidence.[161] As both the court of appeals and the Restatement remind us, "the plaintiff need not prove his case beyond a reasonable doubt. In fact, 'He is not required to eliminate entirely all possibility that the defendant's conduct is not a cause.' "

> It is enough that he introduces evidence from which reasonable men may conclude that it is more probable that the event was caused by the defendant than that it was not. The fact of causation is incapable of mathematical proof, since no man can say with absolute certainty what would have occurred if the defendant had acted otherwise. If, as a matter of

> ordinary experience, a particular act or omission might be expected to produce a particular result, and if that result has in fact followed, the conclusion may be justified that the causal relation exists. In drawing that conclusion, the triers of fact are permitted to draw upon ordinary human experience as to the probabilities of the case.

Yazzie v. Sullivent, 561 F.2d 183, 187 (10th Cir. 1977) quoting Restatement (Second) of Torts § 433B comment b (1965); accord, W. Prosser, Handbook of the Law of Torts 242 (4th ed. 1971).

B. The Problem of Mathematical Proof

In a case where a plaintiff tries to establish a factual connection between a particular "cause" and a delayed, non-specific effect such as cancer or leukemia, the strongest evidence of the relationship is likely to be statistical in form. Where the injuries are causally indistinguishable, and where experts cannot determine whether an individual injury arises from culpable human cause or non-culpable natural causes, evidence that there is an increased incidence of the injury in a population following exposure to defendant's risk-creating conduct may justify an inference of "causal linkage" between defendant's conduct and plaintiff's injuries. See Delgado, "Beyond Sindell: Relaxation of Cause-in-Fact Rules for Indeterminate Plaintiffs," 70 Cal. L.Rev. 881, 884-86 (1982). The search for increased incidence of injury among groups receiving more or less radiation exposure is the classic approach to researching induction of cancer and leukemia by ionizing radiation. See e.g., J. Gofman, Radiation and Human Health (1981), PX-1046, and the studies discussed therein; Hiroshima and Nagasaki, supra at 187-332; the UNSCEAR Report (1977), PX-706/DX-605; the BEIR-III Report (1980), DX-1025. Where there is an increase of observed cases of a particular cancer or leukemia over the number statistically "expected" to normally appear, the question arises whether ir may be rationally inferred that the increase is causally connected to specific human activity. The scientific papers and reports will often speak of whether a deviation from the expected numbers of cases is "statistically significant," supporting a hypothesis of causation, or whether the perceived increase is attributable to random variation in the studied population, i.e., to chance.

The mathematical tests of significance commonly used in research tend to be stringent; for an increase to be considered "statistically significant," the probability that it can be attributed to random chance usually must be five percent or less ($p = 0.05$). In other words, if the level of significance chosen by the researcher is $p = 0.05$, then an observed correlation is "significant" if there is 1 chance in 20—or less—that the increase resulted from chance. H. Young, Statistical Treatment of Experimental Data 131-32 (pap. ed. 1962). In scientific practice, levels of significance of 0.01 to 0.001 are used providing an even more stringent test of a chosen hypothetical relationship. R. Burington & D. May, Handbook of Probability and Statistics with Tables 228 (2d ed. 1970). Where $p = 0.01$ or 0.001, the probability that the observed correlation resulted from random chance is 1 in 100, or 1 in 1,000, respectively. Whether a statistical increase or relationship is "significant" depends first upon what arbitrary level of significance a researcher has selected in analyzing the data. A researcher selecting an arbitrary level $p = 0.05$ has determined that where the probability is 1 in 20 that something resulted from random chance (and, conversely, that the probability is 19 out of 20 that it did not result from chance), the relationship will be deemed "significant"; where, for instance, the probability is 1 in 19 that events happened by chance ($p = 0.0526$), the relationship will be deemed statistically "insignificant"—even though the probability is 94.73% or 18 chances out of 19 that the observed relationship is not a random event. Though deemed "insignificant" by the researcher, the certainty that the observed increase is related to its hypothetical cause rather than mere chance is still far more likely than not. Perhaps an accurate method of reporting would be to indicate at what level of certainty the statistical relationship is "significant." See J. Gofman, Radiation and Human Health 811-12 (1981), PX-1046. This would permit more immediate evaluation of the degree of certainty or randomness that is involved. The cold statement that a given relationship is not "statistically significant" cannot be read to mean "there is no probability of a relationship." Whether a correlation between a cause and a group of effects is more likely than not—particularly in a legal sense—is a different question from that answered by tests of statistical significance, which often distinguish narrow differences in degree of probability.

The inherent limitations in the concept of statistical significance are particularly important to the evaluation of statistical studies of relatively small populations, or groups of subjects.

In a large population, random variations tend to cancel each other out, yielding an overall observed distribution that is far more useful in evaluating correlations, relationships and probabilities. This may be demonstrated through the simple tossing of a coin.

Theory tells us that the probability of a flipped penny turning up "heads" is 1 out of 2, or 50 percent (P(heads) = 0.50). Actually flipping the penny a few times permits chance to operate in a "significant" fashion. A penny flipped 10 times may turn up "heads" 7 times. Flipped 10 more times it may turn up "heads" only 4 times. Nothing about the mathematics of probabilities requires that in actual trials, a coin turn up "heads" every other time. Relying upon our small number of trials, the observed rate of "heads" is 11/20, or 55 percent (R(heads) = 0.55), based upon an observed excess of one case. Suppose we penny-flip one hundred times, turning up 52 "heads"; the number of excess cases has doubled, yet the rate of excess has drawn closer to our theoretical probability(R(heads) = 0.52). Ten thousand penny flips may result in an actual excess of 20 "heads"—a rate even closer to theoretical probability (R (heads) = 0.5020) even though the actual number of excess heads is greater. While the rate of excess "heads" was noticeably greater in the small sample of penny flips (R - 0.55 compared to 0.502, or the thoretical 0.500), the actual excess—one "heads"—is easily attributed to chance. Our confidence in theory is unshaken. Had the larger sample of 10,000 penny flips turned up 520 excess "heads" (R(heads) = 0.552), a more critical reevaluation of theory might be called for. See H. Young, Statistical Treatment of Experimental Data 23-24 (pap. ed. 1962). In simple fashion the process of penny-flipping highlights a limitation of statistical work in small communities: "The fluctuations of pure chance cancel each other out when large numbers are dealt with, but these fluctuations can remain when only small numbers are involved. This is commonly referred to in science as 'the small numbers problem.'" J. Gofman, Radiation and Human Health 147 (1981) PX-1046. Small communities or groups of peo-

ple are deemed "statistically unstable." Id.; BIER III Report (1980), DX-1025, at 237 (statement of Edward Radford, M.D.). Where the normal incidence of a particular cancer in a specific age group in a large population is 50 cases per 100,000 persons, the probable incidence in a population of 1,000 would be 0.5 cases. It's absurd to talk of one-half a case of cancer. There will likely be one case, or none at all. But what would two cases signify? Or three? Random chance operating in a small group, or a doubling or tripling of cancer incidence by a suspected carcinogenic agent? The methods of the statistician approach such data with deliberate caution. Compare e.g., G. Caldwell, et al., "Leukemia Among Participants in Military Maneuvers at a Nuclear Bomb Test," 244 J. Am. Med. Assoc. 1575 (Oct. 3, 1980), PX- 829(B) with G. Caldwell, et al., "Mortality and Cancer Frequency Among Military Nuclear Test (Smoky) Participants, 1957 through 1979," 250 J. Am. Med. Assoc. 620 (Aug. 5, 1983), DX-1243.

That data from small populations must be handled with care does not mean that it cannot provide substantial evidence in aid of our effort to describe and understand events. Mathematical or statistical evidence, when properly combined with other varieties of evidence in the same case can "supply a useful link in the process of proof." Tribe, "Trial by Mathematics: Precision and Ritual in the Legal Process," 84 Harv. L. Rev. 1329, 1350 (1971). If relied upon as a guide rather than as an answer, the statistical evidence offered in this case provides material assistance in evaluating the factual connection between nuclear fallout and plaintiffs' injuries.

The value of the available statistical data concerning radiation and cancer in off-site communities is not confined by arbitrary tests of "statistical significance." Nor is the court constrained by simplistic models of causal probability impressed upon the judicial "preponderance of the evidence" standard.

It is suggested, for example, that in the following scenario plaintiff's proof would fail to satisfy the standard:

> Before the defendant's arrival, the region experienced a stable ("background") rate of 100 cases of the injury per

> year. After the defendant's arrival, the number of cases increases to 190 and remains constant. Expert testimony establishes that the increased incidence of the injury can only be attributed to the conduct of the defendant. . . .

Delgado, "Beyond Sindell: Relaxation of Cause-in-Fact Rules for Indeterminate Plaintiffs," 70 Cal. L. Rev. 881, 885 (1982) (footnotes omitted). In such a case, it is argued, "no victim can make it appear more probably than not that his or her injury stemmed from defendant's conduct." Id. at 887. "[S]uch evidence says little about the cause of the plaintiff's particular injury: Unless that statistical increase is greater than 100%, his injury probably was not caused by the exposure, and he will recover nothing." Note, "Inapplicability of Traditional Tort Analysis," supra, 35 Stan. L. Rev. at 584 (footnote omitted).

First, such argument assumes the absence of other factual connections tying the increased risk to plaintiff's particular injury. Yet even standing alone, the statistical evidence in the hypothetical cases plainly establishes the defendant's probable contribution of approximately 90 additional injuries to the community—a substantial factual connection. Whether causal inferences should be drawn which will carry the case to the additional issues of risks, scope of duty and culpable breach of duty, e.g., negligence, is a question of judgment resting in part upon policy. The court must determine those risks for which the defendant should be held responsible. Malone, "Ruminations on Cause-In-Fact," 9 Stan. L. Rev. 60 (1956); see O'Toole, "Radiation, Causation and Compensation," 54 Geo. L. J. 751 (1966). Whether the defendant is ultimately held responsible for an injury which may likely have occurred anyway is inherently a question of policy, not of factual connection or causation. See Thode, "The Indefensible Use of the Hypothetical Case to Determine Cause-in-Fact," 46 Tex. L. Rev. 423 (1968). The mechanical application of a "greater-than-100%-increase" test in this context represents merely the refabrication of the "but-for" test of causation in mathematical form: but for defendant's 50 plus percent share of the statistically identified injuries, plaintiff would probably not have been hurt.

In cases where, as here, defendant's duty extends to protection

of plaintiff from even the possibility of harm, or where, as here, defendant's wrongful conduct arguably has denied to plaintiff a potential opportunity to avoid serious or lethal injury, analysis using "but-for" tests in any form falls far short of the mark. See Malone, supra, at 77-91.

Two centuries of experience in tort law teach us that "[a] victim's hurt as the result, at least in part, of a defendant's conduct may be highly improbable and yet admittedly true, while on the other hand it may be highly probable and yet the result of other cause factors." Green, "The Causal Relation Issue in Negligence Law," 60 Mich. L. Rev. 543, 557 (1962). Like statistical significance, mathematical probability aids in resolving the complex questions of causation raised by this lawsuit, but is not itself the answer to those questions.

C. The Problem of Dose-Response Relationship

Evaluation of the factual connections and causal linkages between conduct and injury in this case necessarily involves some treatment of the question of the relationship between radiation exposure and human cancer and leukemia. If, for example, the evidence persuasively demonstrated that no long-term biological injury is identified in persons receiving doses of ionizing radiation smaller than 100 rads, statistical incidence or other factual connections would simply be irrelevant, unless each plaintiff could establish the likelihood of a higher radiation exposure.

In DeVere v. Parten, 222 Minn. 211, 213 N.W.2d 584 (1946), the plaintiff alleged that her disability and permanent paralysis due to nerve damage resulted from occupational exposure to carbon tetrachloride fumes. While a causal connection between transverse myelitis and carbon tetrachloride inhalation had not been previously proven, plaintiff sought to establish a relationship between exposure and injury by excluding by evidence all other known cause of the disease. However, expert medical testimony showed that to be harmful, the chemical must be present in a concentration of 100 parts per 1,000,000 parts of air. Evidence in the record indicated a work place concentration of less than 2 percent of this "threshold" concentration. Finding no causal connection, the

court held against plaintiff. Id.; see also Morris, Torts 164 et seq. (1953). Were such an exposure "threshold" demonstrated to exist for ionizing radiation, the task of sifting the evidence in this case would be greatly simplified.

Although some scientists and commentators have at times suggested the presence of a "threshold" dose, the predominant philosophical approaches to radiation protection have carefully eschewed such a view, and the overwhelming weight of currently available scientific evidence supports the view that at any exposure level, ionizing radiation causes some degree of biological damage and creates some long-term risk of cancer and leukemia in those persons who are exposed. This court has carefully reviewed the major recent studies of health effects of low-level ionizing radiation, e.g., the UNSCEAR Report (1977), PX-706/DX-605, the BEIR-III Report, DX- 1025, J. Gofman, M.D., Radiation and Human Health (1981), PX-1046, as well as the numerous articles offered into evidence by the parties. E.g., Upton, "The Biological Effects of Low-Level Ionizing Radiation," 246 Scientific American 41 (Feb. 1982), DX-1142. While there remains considerable uncertainty—and controversy—surrounding the precise quantitative mathematical description of the dose-response relationship for various radiations and cancers, none of the recent studies offer any direct evidentiary support for a threshold dose below which exposure is "safe," harmless and without additional risk.[162]

The exact relationship between radiation exposure and additional risk of cancer or leukemia appears to be dependent upon a number of variable factors, some known and some unknown. For one thing, "too little is known about the mechanisms of radiation carcinogenesis for dose-response models to be specified with any certainty," at least from a theoretical standpoint. BIER-III Report, at 136-37 (1980) DX-1025. "We may not know for decades or centuries the intimate cellular details of precisely how ionizing radiation causes cancer,. . . " J. Gofman, M.D., Radiation and Human Health 102 (1981), PX-1046. In the absence of a proven mechanical description of cancer induction, we may reasonably rely on observed relationships between exposure and incidence of somatic effects. From the empirical evidence, we know that "age at exposure to ionizing radiation is a major factor in the car-

cinogenic response." BIER-III Report, at 167 (1980), DX-1025. For many cancers, "[t]he cancer risk from radiation is much greater for those irradiated at 0-9 years of age than for those irradiated at 10-19 years of age, and the risk declines even further for those irradiated at higher ages." J Gofman, M.D., Radiation and Human Health, at xv (rev. ed. 1983). The evidence establishes that cancer may be induced by radiation in nearly all the tissues of the human body, BIER-III Report at 137 (1980), DX-1025, but that tissues and organs vary considerably in their sensitivity to the induction of cancer by radiation. Id. In general terms, Table 15 catalogues the differences in organ and tissue sensitivity to radiation exposure.

BIER-III Report, at 266-267 (1980), DX-1025; accord, UNSCEAR Report 25 at 6, 309-319 at 413-414, PX-706/DX-605. The empirical evidence indicates that

> With respect to excess risk of cancer from whole-body exposure to radiation, solid tumors are now known to be of greater numerical significance than leukemia. Solid cancers characteristically have long latent periods; they seldom appear before 10 years after radiation exposure and may continue to appear for 30 years or more after radiation exposure.

BIER-III Report, at 137 (1980), DX-1025. The problem of the latency period requires careful handling of both empirical evidence and the statistical studies in the literature. The importance of extended follow-up examination of an exposed population should not be underestimated.

For example, when more than 200 residents of the Marshall Islands were exposed to significant levels of fallout radiation from the March 1, 1954 BRAVO thermonuclear explosion at Bikini Atoll in the Pacific, medical surveys of the Marshallese conducted two[163] and four years later[164] reported no incidence of tumor or malignancy among those exposed to fallout. None other than Dr. Edward Teller, "father" of the hydrogen bomb, wrote an article for Life magazine reassuring the readers that "all of the Marshallese and American victims seem to be fully recovered from a dosage of radioactivity far greater than any humans are ever likely to be subjected to again from a bomb test. Although long-term

effects are still being carefully watched for," Teller reported, "no malignancies or cases of leukemia have shown up to date." E. Teller & A. Latter, "The Compelling Need for Nuclear Tests," Life, Feb. 10, 1958, in L. Young, ed., The Mystery of Matter 582, 588 (1965). "What happened to them," Teller asserted, "is the best indication we have of the long-term effects of substantial radiation exposure." Id.

Twenty-two years later, 40 of the Marshallese had developed thyroid nodules, 7 of them cancerous. See BEIR-III Report at 296 (1980), DX-1025 and studies cited therein. Those of the thyroid cancers had not appeared as late as 1970. R. Conrad, M.D., et al., "Thyroid Neoplasia as Late Effect of Exposure to Radioactive Iodine in Fallout," 214 J. Am. Med. Ass'n 316-324 (1970). Further study continues. See R. Conrad, M.D., et al., "Thyroid Hypofunction After Exposure to Fallout From a Hydrogen Bomb Explosion," 247 J. Am. Med. Ass'n 1571-75 (1982). The problem of latency period is compounded in reference to the plaintiffs herein; potential dates of injurious exposure include 1951, 1952, 1953, 1955, 1957, 1958, 1961, and 1962.[165] Latency periods for NTS fallout-induced cancers should be analyzed in terms of a range of times of exposure that seems logical under particular circumstances.

The empirical evidence also indicates that the incidence of radiation-induced breast and thyroid cancer is such that the total cancer risk is greater for women than for men. Age again is important: women exposed at 10-19 years of age have the highest risk of radiation-induced breast cancer. With respect to other cancers, the radiation risks for both sexes are approximately equal. BIER-III Report at 137-38 (1980), DX-1025.

Additional factors have been identified, yet remain shrouded in mystery. It is postulated that various internal or environmental factors may interact with radiation in a manner that affects cancer incidence in different tissues. These may include hormones, other carcinogenic agents, immunological factors, genetic abnormalities, or other stimuli of rapid cell growth. Id. DX-1025, at 33, 138. Without a complete description of the mechanism of cancer causation, the importance of these factors is impossible to accurately assess. The role of cellular "repair" mechanisms[166] in reducing

TABLE 15.

Sensitivity of Various Tissues to Oncogenic Influence of Radiation

Site or Type of Cancer	Spontaneous Incidence of Cancer	Relative Sensitivity to Radiation Induction of Cancer	Remarks
Major radiation-induced cancers			
Female breast	Very high	High	Puberty increases sensitivity
Thyroid	Low	Very high, especially females	Low mortality rate
Lung (bronchus)	Very high	Moderate	Quantitiative effect of smoking uncertain
Leukemia	Moderate	Very high	Especially myeloid leukemia
Alimentary tract	High	Moderate to low	Occurs especially in colon
Minor radiation-induced cancers			
Pharynx	Low	Moderate	—
Liver and biliary tract	Low	Moderate	—
Pancreas	Moderate	Moderate	—
Lymphomas	Moderate	Moderate	Lymphosarcoma and multiple myeloma, but not Hodgkin's disease
Kidney and bladder	Moderate	Low	—
Brain and nervous system	Low	Low	—
Salivary glands	Very low	Low	—
Bone	Very low	Low	—
Skin	High	Low	Low mortality. High dose necessary?

Sensitivity of Various Tissues to Oncogenic Influence of Radiation

Site or Type of Cancer	Spontaneous Incidence of Cancer	Relative Sensitivity to Radiation Induction of Cancer	Remarks
Sites or tissues in which magnitude of radiation-induced cancer is uncertain			
Larynx	Moderate	Low	—
Nasal sinuses	Very low	Low	—
Parathyroid	Very low	Low	—
* Ovary	Moderate	Low	—
Connective tissues	Very low	Low	—
Sites or tissues in which radiation-induced cancer has not been observed			
Prostate	Very high	Absent?	—
Uterus and cervix	Very high	Absent?	—
Testis	Low	Absent?	—
Mesentery and mesothelium	Very low	Absent?	—
Chronic lymphatic leukemis	Low	Absent?	—

radiation damage in the biological microcosm is also unknown. Finally, whether the rate of exposure may decrease the incidence of radiation-induced cancer or leukemia remains in some question. The BIER-III Report comments:

> Reductions in dose rates may decrease the observed radiation effect per unit dose, particularly for larger doses of low-LET [B-$_s$y], radiation but not for doses in the linear portion of the linear-quadratic dose-response model and not for high-LET [a<,] radiation. There appear to be mechanisms, however, pertaining especially to exposure to high-LET radiation, that increase the observed effect per unit dose when the dose rate is reduced. The Committee recognizes that dose rate may affect the risk of cancer induction, but believes that the information available on man is insufficient to adjust for it.

Id. DX-1025, at 3 (emphasis added). Contrary to the confident assertions of the Government's fallout pamphlets that radiation taken in small doses presents no hazard,[167] it appears that the opposite may be the case where long-term somatic injuries are concerned.[168] As Gofman points out, at the cellular level, an energy transfer is an energy transfer; the total number of disrupted molecules may likely be the same whether ionized over a shorter or longer period of time. J. Gofman, M.D., Radiation and Human Health 404-07 (1981) PX-1046. Biological damage to cell mechanisms caused by ionizing radiation may well prove cumulative to a great extent. See e.g., BIER-III Report, supra at 281.

When these variables are considered together, it is readily apparent that the dose-response relationship between ionizing radiation and cancer may vary according to (1) type of radiation; (2) type of cancer; (3) personal variables of the exposed individual (age, sex, physical characteristics); and (4) interactions when other stimuli or environmental factors. Yet when analyzed in light of these variables, the empirical evidence appears to offer a sufficient basis for at least a qualified generalization about the proportionality of dose and response. Several mathematical models have been suggested. See Fig. 12.

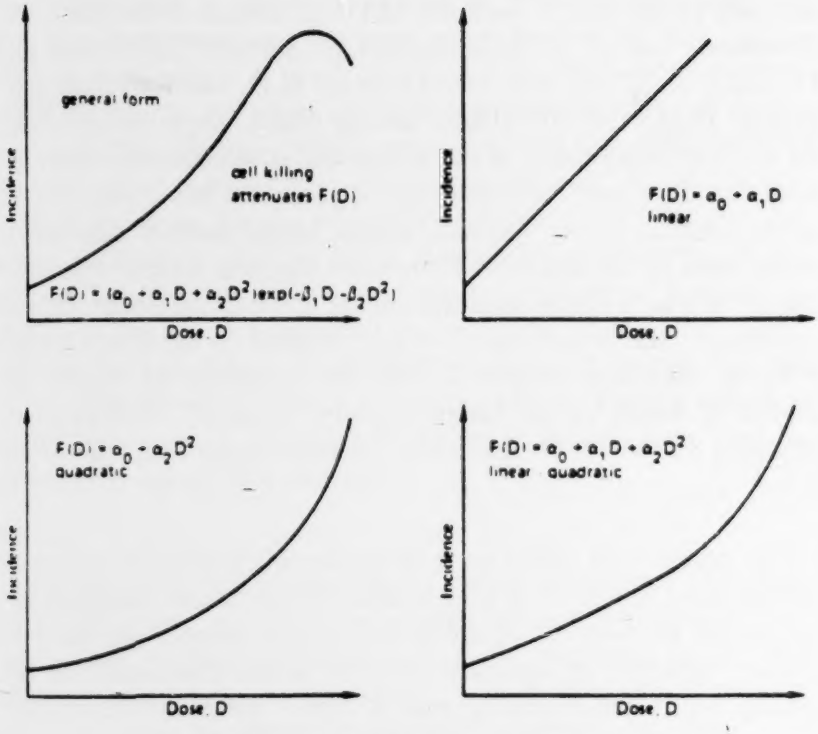


FIGURE 12. Alternative dose-response curves.

BIER-III Report, at 23 (1980), DX-1025.

In 1980, a majority of the BIER-III Committee reached general agreement that "for most radiation-induced solid cancers the dose response relationship for low to intermediate doses of low-LET radiation is best described by a linear-quadratic function of dose. . . ," a compromise permitting the Committee to "present an envelope of estimates bounded by the linear and pure quadratic models, with the linear-quadratic providing intermediate values." BIER-III Report, supra, at 142. Where compelled by experimental or epidemiological data, the Committee conceded that the dose response relationships for high-LET radiation and human breast cancer, for example, are probably linear if not supralinear (i.e., reflecting greater risk of somatic injury per rad at lower doses) in nature.[169] In fact, in the linear-quadratic model, the linear component is dominant at low doses. Id. DX-1025 at 190. Separate

analyses by Edward P. Radford, M.D., Chairman of the BIER-III Committee and of its Subcommittee on Somatic Effects, see Id. DX-1025, at 227-53, and John Gofman, M.D., see Radiation and Human Health 368-415 (1981), among others, argue persuasively for a linear relationship, if not a supralinear relationship, between radiation dose and increased risk of cancer at low doses. More recent analysis of the Nagasaki atomic bomb survivor data often relied upon by the BIER-III Committee supports a linear relationship or at least a linear-quadratic model in which the linear term is significant. See Wakebayashi, et al., "Studies of the Mortality of A-Bomb Survivors: Report 7: Part III. Incidence of Cancer in 1959-1978, Based on the Tumor Registry, Nagasaki," 93 Radiation Research 112-46 (1983) quoted in Gofman, supra (rev. ed. 1983) at xvi.

This court is not called upon to resolve this protracted scientific debate; nor could it do so even if asked. Nevertheless, the terms of the debate persuasively establish the general proposition that increased exposure to ionizing radiation yields increased risk of human cancer and leukemia, even at "low" doses and dose rates.

The terms of the debate are the important thing. Whether there is increased risk from increased exposure even at "low" doses is not hotly contested; the question is how much additional risk. However modeled, a proportional dose-response relationship lends great credence to a simple concept expressed by Radford:

> [O]ne may conclude that in human studies where a small excess of cancer is found at a particular dose of radiation but is borderline in statistical significance, it is prudent to consider the effect may be real rather than to dismiss the study as negative.

BIER-III Report, supra, DX-1025, at 243 (emphasis added).

D. The Problem of Dosimetry

Even under controlled laboratory conditions, accurate determination of absorbed dosages of radiation in human tissue is problematical.[170] Usually where the question of radiation-induced can-

cer or leukemia is raised, dose must be estimated long after the fact of actual exposure. Accurate reconstruction of dose proves difficult even when a good deal is known from measurements about the source, the times and extent of exposure, effect of shielding, and other factors. Where measurements are scarce or nonexistent, dose estimation is exceedingly difficult. Reconstruction of dose estimates for the people of Hiroshima and Nagasaki was accomplished in part by using simulation experiments at the Nevada Test Site exposed to real nuclear explosions. It would be absurd at this point to reconstruct the estimated exposure of off-site residents to fallout by detonating additional atomic weapons in the open air to reproduce the fallout effects. Current efforts at dose reconstruction have turned instead to far less direct and far more subtle means and methods.

The record in this action offers a variety of evidence concerning dosimetry. First, of course, are offered the contemporaneous external gamma exposure estimates originally calculated by the NTS off-site radiation safety personnel, with built-in pre-adjustments for attenuation by shielding, distance, geometry, etc. based upon generalized assumptions. There is the limited film badge data on off-site residents gathered beginning in TEAPOT (1955) and PLUMBBOB (1957), with some analysis in terms of overall population dosages.[171] There is the testimony of Joann Workman and others, offered by the plaintiffs as "human dosimeter" witnesses to demonstrate through observed events and remembered symptoms a pattern of acute injuries arguably consistent with much higher absorbed external doses than estimated by the Government calculations.[172] The record includes testimony by Elbridge Morrill, Jr., who in 1953 was Director at the Utah State Division of Occupational Health and who used radiation instruments to measure exposure rates of more than 5,000 milliroentgens per hour as a cloud of dust enveloped the highway on which he was travelling a few miles from St. George. Tr. at 2678, 2684, et seq. The plaintiffs have also offered testimony by Tamplin, Gofman, Knapp and others reviewing and evaluating the available dosimetry and statistical information. See Tr. at 2270-2434 (testimony of Dr. Arthur R. Tamplin); Tr. at 2447-2669 (testimony of Harold A. Knapp); Tr. at 3413-17, 3449-54 (testimony of Dr. John Gofman).

The Government produced published studies and expert testimony concerning the present location and concentration of trace amounts of long-lived fallout residues, such as cesium-137 and plutonium-239, in soil sampled at various locations.[173] It also produced evidence concerning the current Off-Site Radiation Exposure Review Project (ORERP) and the efforts of Church, Whicker, Anspaugh, Smale, and others to reconstruct external and internal dose estimates using the few measurements available in conjunction with theoretical models and data from other sources and events.[174] Transcripts of sessions of the Dose Assessment Advisory Group (DAAG) at which that work was described, reviewed and criticized have also been provided.[175]

This court has carefully reviewed the testimony and documentary evidence offered as relating to dosimetry. Even as much recent work as has been done still leaves the question of radiation exposure of individual plaintiffs very much in doubt. Even upon the completion of current studies by Wrenn and others,[176] the exact dose of radiation delivered to individuals or to the group will never be known with precision. As the BIER-III Committee points out, "This problem is common to all retrospective studies of effects of environmental agents on human populations." BIER-III Report, supra DX-1025, at 29. Yet it is particularly evident here, where the extended period of repeated, uneven exposures to off-site fallout alone renders the processes of estimation far more complex than those for single-exposure events, such as Hiroshima and Nagasaki, or the Windscale incident in Great Britain, or the Three Mile Island incident in Pennsylvania.[177]

As with statistical evidence, however, the court is not confined solely to contemporaneous or reconstructed dosimetry estimates in determining whether to draw the inference that the defendant's negligent conduct has been a "substantial factor" contributing to the plaintiffs' injuries. As the BIER-III Committee observed:

> Despite these problems with radiation dosimetry in retrospective studies, determination of excess cancer is generally of value, even in groups lacking dose estimates. Such studies may give the first indication that the rate of a particular cancer has increased or that there is consistency among sev-

> eral studies of the types of cancer observed. Finally, information can sometimes be obtained about the latent period. Studies that produce inconsistent results suggest that radiation exposure is not a principal causative factor or that other factors have a role in carcinogenics. A degree of consistency of results in a large number of studies constitutes major support for defining somatic risks.

BIER-III Report, supra, DX-1025 at 29-30. The record in this action runs to neither extreme; there is some evidence pertaining to dose accompanied by some evidence pertaining to increased statistical incidences of various consistent injuries.

The Government implicitly and explicitly urges the conclusion that its estimates of fallout exposure to the plaintiffs—educated guesses, really—represent the probable upper limits of the radiation dosage and corollary risk of cancer and leukemia actually experienced by the plaintiffs. Months of review of the record and exhibits in this action compels this court to find otherwise. Rather than serving as the ceiling of retrospective dosimetry for many of the plaintiffs, the exposure estimates currently offered by the Government should likely be deemed to be minimum figures for use in risk estimation. While without question some individuals received less exposure than is currently estimated, it is extremely likely that many people received more exposure to alpha, beta and gamma radiation both externally and internally than more conservative guesses have indicated. Particularly where people were not adequately instructed as to precautions that would significantly minimize total exposure, it seems unreasonable to assume that exposures to everyone were fortuitously minimized by factors 2, 3, 5 or 10 by events and circumstances left to random chance. Careful analysis of the limited film badge data available from the "low-fallout" PLUMBBOB series indicates otherwise.[178] So does the novel "reverse engineering" approach presented by plaintiffs through the testimony of Dr. John Gofman. Gofman applied the linear dose-response model to the evidence of increased cancer incidence reported by the Johnson survey[179] to retrospectively estimate the dose that would account for the observed increase. The dose estimates so arrived at are substantially in excess of those offered by the Government. Table 16 compares the organ doses (in

rads) calculated by the ORERP and by Gofman and the external whole-body exposure (in Roentgens) calculated by Beck and Krey for the Government[180] and by Tamplin for the plaintiffs: [see page 272].

While certainly not controlling, the Gofman analysis further butresses the conclusions reached by this court upon review of other evidence in this case.

Recognizing that cancer and leukemia may be caused by radiation from other sources (natural, medical, occupational, etc.) or by other carcinogenic agents, exposure to nuclear fallout proves to be a likely "substantial factor" where the dosage materially exceeds that which is received from other sources, such as natural "background" radiation and medical x-rays or other radiological treatments. Increased incidence of injuries consistent with such exposure, particularly in radiosensitive tissues and persons, adds additional weight to the argument that the observed injuries are a real effect of radiation exposure from the additional source. Radiation exposure higher than "background" dose is the first of the factual connections set forth above that a plaintiff must establish.

All of the relevant factual connections, including dosimetry, should be considered in the evaluation of the likelihood of a relationship between fallout and cancer as to each plaintiff. Where it appears from a preponderance of the evidence that the conduct of the defendant significantly increased or augmented the risk of somatic injury to a plaintiff and that the risk has taken effect in the form of a biologically and statistically consistent somatic injury, i.e., cancer or leukemia, the inference may rationally be drawn that defendant's conduct was a substantial factor contributing to plaintiff's injury. Unless the facts are proven otherwise by sufficient evidence, the inference provides a rational basis for imposing liability, depending upon the determination of other issues (scope of duty, negligence, etc.).

E. "Substantial Factor" Determinations

In each of the 24 cases now before this court, the plaintiffs must establish by a preponderance of the evidence that (1) the decedent

or living plaintiff having cancer was probably exposed to fallout radiation significantly in excess of "background" radiation rates; (2) the injury is of a type consistent with those known to be caused by ionizing radiation; and (3) that the person injured had resided in geographical proximity to the Nevada Test Site for some if not all of the years of atmospheric testing between 1951 and 1962. If these factual connections are established, other relevant factors will also be evaluated in determining the "substantial factor" issue.

In the following cases, (1) through (3), the plaintiffs have failed to establish the second factual connection, consisting of injury with a radiation "cause."

(1.) LIONEL WALKER

Lionel Walker was diagnosed on March 4, 1977 as having an adenocarcinoma of the prostate. At the time of diagnosis, Mr. Walker was 50 years old. He was at least 25 years old during the period of atmospheric nuclear testing in Nevada.

Apart from the general axiom that "[c]ancer may be induced by radiation in nearly all the tissues of the human body," BIER-III Report, supra, DX-1025, at 137, this court can find no epidemiological study or other human evidence establishing a relationship between adenocarcinoma of the prostate and exposure of ionizing radiation. The major collective studies, e.g., UNSCEAR, BIER-III, and Gofman, are essentially silent on the subject. Hiroshima and Nagasaki (1981) reviews the Japanese data and finds no relationship.[181]

Based upon the record, the court concludes that Mr. Walker's injury has not been established to be consistent with causation by radiation exposure by a preponderance of this evidence.

(2.) WILLIAM W. SWAPP

At the age of 52, William W. Swapp was diagnosed as having a sarcoma of the kidneys on June 22, 1971. The sarcoma is specifically identified as an embryonal rhabdomyosarcoma, also referred

TABLE 16.*

PLAINTIFF	RELEVANT ORGAN	GOFMAN (rads)	ORERP (rads)	TAMPLIN (Roentgens)	BECK AND KREY (Roentgens)
Donna Berry	Ovaries	36.7	0.25	1.259	0.6
Willard Bowler	Skin	237.3	310	—	—
Delsa Bradshaw	Lung	36.7	0.47	1.413	3.7
Jeffery Bradshaw	Lymphatic S.	24.6	0.52	1.259	0.6-3.7
Arthur Bruhn	Bone Marrow	18.2	1.8	8.283	3.7
John Crabtree	Bone Marrow	18.2	0.36	1.259	0.6
Karlene Hafen	Bone Marrow	8.1	2.2	7.322	3.7
Glen Hunt	Pancreas	29.4	0.42	0.628	0.6
Sybil Johnson	Bone Marrow	18.2	0.45	1.259	0.6
Lenn McKinney	Bone Marrow	18.2	1.7	3.395	—
Sheldon Nisson	Bone Marrow	14.1	2.8	8.283	2.4
Melvin Orton	Stomach	36.7	0.39	—	1.1
Peggy Orton	Bone Marrow	14.1	0.50	1.259	1.1
Lisa Pectol	Brain	22.0	0.60	1.271	3.7
Daisey Prince	Lymphatic S.	36.7	0.44	1.259	0.6
Norma Pollitt	Breast	36.7	0.38	1.259	0.6
Jacquelynn Sanders	Thyroid	717.6	31	—	—
William Swapp	Kidney	20.0	3.7	7.322	3.7
LaVier Tait	Bone Marrow	20.2	2.0	3.395	—
Geraldine Thompson	Ovaries	29.4	0.28	1.259	0.6

PLAINTIFF	RELEVANT ORGAN	GOFMAN (rads)	ORERP (rads)	TAMPLIN (Roentgens)	BECK AND KREY (Roentgens)
Lionell Walker	Prostate	14.7	0.69	1.350	—
Kent Whipple	Thorax	36.7	0.69	1.630	—
Irma Wilson	Bladder	36.7	2.5	8.283	3.7
Catherine Wood	Colon	36.7	0.43	1.259	0.6

*[ORERP calculated total rad doses to organs including those from both internal and external sources [see DX-1169]; Beck and Krey calculated exposures in roentgens for people living in different cities in Utah, no values are listed here for people living outside Utah [see DX-1110]; Dr. Gofman calculated total absorbed doses in rads to the affected organs [see DX-1086]; Dr. Tamplin estimated external exposures in roentgens. [See PX-998 through 1003].]

to as an adult Wilms tumor. Tr. at 5263-64.[182] In Radiation and Human Health, Dr. John Gofman briefly describes the strong correlation between Wilms tumor and congenital genetic injury:

Wilms Tumor

> This is a cancer of the kidney, or of the tissues around the kidney. It is a strange tumor, in that it frequently shows completely differentiated tissues, including muscle, cartilage, tissue similar to the lining of the intestine, and other differentiated structures, all within the tumor itself. This tumor can be associated with certain other anomalies, such as aniridia (lack of development of the iris of the eye), genitourinary abnormalities, and mental retardation. One such grouping, studied carefully by Riccardi and co-workers (1978), is called the AGR triad, which shows aniridia, Wilms tumor, and abnormal genitalia. Through the use of banding techniques, Riccardi and co-workers found that this triad was associated with an interstitial deletion of the short arm of chromosome 11 (also called C-11). Out of six patients diagnosed as "AGR triad," all six showed the interstitial deletion of chromosome 11. Two of these six patients had already developed a Wilms tumor. It is to be emphasized that all the body cells of such individuals show the deletion, not just the abnormal tissues.
>
> Riccardi studied one pair of identical twins, both of whom showed the deletion, and one of whom already had a Wilms tumor. Since the parents of one case were studied and did not show the deletion, Riccardi concluded that in this case, the deletion must have been acquired in a germ cell (sperm or ovum).
>
> This is remarkable association of a specific chromosome lesion with a high risk of a specific form of cancer. The mechanism of the association remains obscure.

Id. at 98-99 (1981), PX-1046. Other studies correlate Wilms tumor to irradiation of the victim's mother during pregnancy. Id. PX-1046 at 330. Testimony of Dr. John J. Murphy, a specialist in

urology further supports the conclusion that Mr. Swapp's cancer has not been established to be consistent with causation by radiation exposure—at least as a somatic rather than a genetic injury—by a preponderance of the evidence.

(3.) LISA D. PECTOL

The sudden illness and death of Lisa D. Pectol at 20 years of age on November 7, 1976 has tentatively been attributed to a brain tumor. The diagnosis is concededly speculative; no autopsy or biopsy was performed to confirm the diagnosis and establish the primary site of the cancer, if cancer it was. While the type of injury is consistent in broad terms with a radiation etiology, the fact of the somatic injury itself has not been established by a preponderance of the evidence.

In the remaining cases, the evidence in the record establishes the first three factual connections. Proof of additional factual connections which indicate that exposure to fallout materially augmented the plaintiffs' risk of injury, which took effect in actual somatic injury to the plaintiffs, was insufficient or lacking in several more cases.

(4.) DONNA JEAN BERRY

Donna Jean Berry was diagnosed in March of 1977 as having abdominal carcinoma originating in her ovaries and uterus. She died on November 24, 1978.

While cancers of the ovary and uterus have tentatively been associated with exposure to ionizing radiation, the existing human data indicates that the sensitivity of these organs to radiation is considerably lower than other human tissues. See e.g., BIER-III Report, DX-1025, at 406-11. The paucity of evidence of increased incidence of ovarian or uterine cancer in the off-site population as well as the existence of other factors, such as medical irradiation reported in Donna Jean Berry's medical records, adds little to the more general factual connections.[183] The plaintiffs have failed to establish by a preponderance of the evidence that defendant's con-

duct was a "substantial factor" contributing to Donna Jean Berry's cancer.

(5.) GERALDINE THOMPSON

Geraldine Thompson died on December 6, 1973 of ovarian cancer which had spread into her abdomen.

The evidence now in the record fails to establish by a preponderance of the evidence that exposure to fallout radiation as a consequence of the defendant's negligence was a "substantial factor" contributing to her illness. It fails for essentially the same reason as explained in the case of Donna Jean Berry; the correlation between her ovarian cancer and radiation exposure is even more tenuous. See BIER-III Report, supra; see also Tr. at 5219 (testimony of Dr. Cecelia Fenoglio, M.D.).[184]

(6.) DELSA BRADSHAW

On December 6, 1972, Delsa Bradshaw died of metastatic carcinoma of the lung; when the cancer was first detected or detectable is unknown.

A substantial body of human evidence outlines the greater relative sensitivity of lung tissue to radiation exposure, particularly involving inhalation of radon gas or solid particles contaminated with alpha-emitting radionuclides. See e.g., J. Gofman, Radiation and Human Health, 343, 345, 443-68, 477 et seq., PX-1046; BIER-III Report, at 308-28 (1980), DX-1025; UNSCEAR Report at 394-399 (1977), PX-706/DX-605; and studies discussed therein.

The retrospective dose estimates to lung tissue offered in this case by the Government are problematical. See Kent Whipple findings, infra. Even assuming that inhalation exposure has been significantly underestimated, the available data including the survey by Dr. Carl Johnson[185] fails to establish an increased incidence of lung cancer among off-site residents during the 1972-1980 time period. Perhaps an increased incidence will make itself apparent in the near future. In summarizing the Japanese data, the

BIER-III Committee observes:

> The induction of lung cancer depends heavily on age of exposure and duration of observation. Those who were over 50 years old at the time of the bombing had a mortality excess above expectation beginning 10 years after the bombing; those who were 20-34 years old are just beginning to show an excess above expectation 33 years later. . . .
>
> Because excess lung-cancer risk continues beyond 25 yr after exposure and because the lung-cancer effect is only now being expressed in persons exposed before the age of 35, it is evident that future estimates are likely to be somewhat higher than those available now.

BIER-III Report, DX-1025, at 314, 315. Gofman uses a theoretical model of plutonium exposure through inhalation of fallout to predict a considerable future increase in lung cancer incidence. Radiation and Human Health, supra, at 477-520.

That lung cancer connected to fallout exposure may significantly increase in future years, however, weighs against the plaintiff's case; Delsa Bradshaw, thirty years old during UPSHOT/KNOTHOLE in 1953, suffered from lung cancer with a latency period of less than 20 years—a latent period notably uncharacteristic of a radiation etiology if Gofman's projections are correct. If, however, the BIER-III Committee is correct in asserting that for lung cancer, "the minimal latent periods are approximately 15-20 years for those irradiated at the age of 15-34, and 10 years for those irradiated at the age of 35 or above," BEIR-III Report, supra, at 327, an increased incidence should be observable. Apparently, none has appeared.[186]

While it is true that lung or bronchial cancer "has emerged as one of the most important radiation-induced cancers," BEIR-III Report, supra, at 308, the evidence presently in the record fails to establish by a preponderance of the evidence that exposure to fallout radiation was a substantial factor contributing to Delsa Bradshaw's cancer.

(7.) KENT O. WHIPPLE

Kent O'Neil Whipple was born on August 30, 1938. When atmospheric testing began near his home in Hiko, Nevada, he was 12 years old. When it ended in 1962, he was 24. Thirteen years later, in December of 1975, he was diagnosed as having adenocarcinoma of the lung. He died on February 5, 1977, 14 months later. Calculated from 1953, the year of UPSHOT/KNOTHOLE and its heavier patterns of fallout, the latent period of Kent Whipple's cancer would approximate 22 years.

Retrospective dosimetry in this case offers relatively low exposure figures, particularly those estimated by ORERP.[187] But cf. Tr. at 3580 (testimony of Dr. John Gofman). Although close in distance to the NTS, Hiko, Nevada appears to have received intermediate amounts of fallout. Working most often outdoors as a cattle rancher in that vicinity, Kent Whipple was one of those offsite residents who was more likely to come in direct, repeated and continuous contact with fallout residues.[188] The latency period of his cancer is consistent with BEIR-III estimates. As in the case of Delsa Bradshaw, however, the record does not reflect an observed increase in incidence of lung cancer in the local population appearing during the period that Kent Whipple's cancer was detected and diagnosed.

Without more, the record as to Kent Whipple fails to establish a preponderance of the evidence fallout radiation as a substantial factor contributing to his cancer.

A similar paucity of statistical evidence demonstrating an increased incidence of cancer of the bladder, the pancreas, as well as melanoma and Hodgkins disease, characterizes the cases of other plaintiffs.

(8.) WILLARD L. BOWLER

At the age of 56 years, in July of 1967, Willard Lewis Bowler was diagnosed as having a malignant melanoma, a form of skin cancer. He died in December of the same year. As a factual connection, dosimetry in the case of Willard Bowler is strong:

ORERP calculates a dose to his skin of 310 rads. Plaintiff's expert suggested a theoretical estimate of 237.3 rads to the skin.[189] The causal correlation between skin cancers, including melanoma, and exposure to radiation at this point remains tentative. The studies reviewed by UNSCEAR, BEIR-III and Gofman generally have involved larger doses of radiation to the skin in medical irradiation situations. Data concerning the Japanese and Marshallese show little incidence of skin cancer, though differences in skin pigmentation and radiosensitivity may account for this. See BEIR-III Report (1980) DX-1025, at 426-41; UNSCEAR Report (1977), PX-7061/DX-605 ¶ ¶ 293-302 at 411-12. The UNSCEAR Report summarizes the data as to observed latency periods in a range of average latencies from 27, 27.5 and 31 years to 41.5 years in one study. Id. at ¶ 302. This contrasts with a latency period calculated for Mr. Bowler ranging from 9 to 16 years. In the eight-year period immediately preceding his diagnosis, the Johnson survey reports 3 observed melanoma when 1.9 were expected. This "increase" is not nearly as significant as the one reported for 1972 to 1980, and may entirely reflect the whim of chance. As a farmer, Willard Bowler spent much time outdoors, exposed on occasion to significant fallout, but also to direct sunlight for extended periods. The potential impact of sunlight as a major contributor, at least among Caucasians, further obscures ionizing radiation from fallout as a causal factor. See also Tr. at 5607-10 (testimony of Dr. Robert Anderson).

While in the case of Willard Bowler, the reconstructed dose evidence is strong, the presence of other, more directly correlated factors, the short latency period and the lack of a meaningful increased incidence of melanoma at the time of his illness weigh against a finding that fallout radiation exposure as a consequence of defendant's conduct represented a substantial factor contributing to Willard Bowler's cancer.

(9.) CATHERINE WOOD

On November 30, 1972, Catherine Wood was diagnosed as having anular carcinoma of the colon. She died on January 23, 1974. While some colon cancers have been identified to ingestion of radium salts or other exposures to radiation, see BEIR-III Re-

port, DX-1025, at 367-372, there is less information upon which to base an inference of relative tissue sensitivity to radiation particularly at low to intermediate dose levels. See UNSCEAR Report (1977), PX-706/DSX-605, ¶ ¶ 266-76 at 407-09, and studies cited therein.

Once more, statistical evidence of a significant increase in colon cancer among off-site residents is sketchy, though the Johnson survey indicates a "statistically significant" increase among Mormon women in southwestern Utah for the period 1972-1980 (11 observed/3.7 expected). In the case of Catherine Wood, however, the presence of intestinal polyps substantially weakens any inference of radiation as a causal factor. See Tr. at 5226-33 (testimony of Dr. Cecelia Fenoglio). The treating physician, a cancer specialist, discounts radiation as a factor in Catherine Wood's cancer, based in part on review of Utah Cancer Registry Statistics. Tr. at 5373 (testimony of Dr. Charles Smart).

Even assuming an absorbed dose considerably greater than the estimates proposed by the parties, the evidence in the record preponderates against fallout radiation as a substantial factor contributing to Catherine Wood's illness and death.

(10.) IRMA L. WILSON

Irma Louisa Nelson Wilson died on January 13, 1978 of uncertain causes. Ten months prior to that, she was diagnosed as having carcinoma of the bladder. The limited human data available points to a probable relationship between exposure to radiation and cancer of the bladder and other urinary organs, though "[t]he degree of susceptibility is probably low, however, in comparison with other organs." BEIR-III Report, DX-1025, at 404; see id. at 400-05. The absence of evidence of increased incidence of bladder cancer among off-site residents as well as the uncertainty of exposure levels renders evaluation of the plaintiffs' claims difficult at best. There is simply not sufficient evidence in the record to permit accurate assessment of the degree of contribution by fallout to the injury in this case.

(11.) JEFFREY BRADSHAW

Jeffrey Bradshaw was born in Cedar City, Utah on November 13, 1953. In January of 1973, at the age of 20, he was diagnosed as having Hodgkin's Disease, a cancer affecting the lymphatic system. While the Japanese data reflects a modest increase in incidence of Hodgkin's Disease, other data gathered following medical irradiation for an illness known as ankylosing spondylitis produced no cases of the disease. See UNSCEAR Report (1977), DX-706/DX-605 ¶ ¶ 286-92 at 410-11. In this case, Jeffrey Bradshaw was probably exposed to some degree of fallout radiation in utero during the UPSHOT/KNOTHOLE in spring of 1953, as well as in the early years of his life during TEAPOT (1955), PLUMBBOB (1957), and HARDTACK II (1958). Fallout radiation is among the possible causes of his Hodgkin's Disease. The absence of specific data demonstrating an increased incidence of Hodgkin's Disease in St. George, in Washington County, or in southwestern Utah may indicate an absence of causal relationship or may reflect the characteristically small number of radiation-caused cases of Hodgkin's Disease in an exposed population. The absence of a perceptible increase in lymphatic cancers among males reflected in the Johnson survey, however, weighs adversely to the plaintiff's claim. Additionally, the population dose calculations suggested for Hodgkin's Disease by Gofman in Radiation and Human Health are significantly higher than those for other lymphatic cancers in an exposed population (10,343 organ-rads per cancer compared to 9,056 organ- rads for multiple myeloma or 3,526 organ-rads for other lymphomas in an exposed population). Id. at 339-42, 344, 360-363. With the additional absence of evidence of increased incidence of other lymphatic cancers, the evidence in the record cannot identify exposure to fallout as a substantial factor contributing to Jeffrey Bradshaw's injury.[190]

(12.) MELVIN O. ORTON

At the age of 32, in February of 1970, Melvin Oscar Orton was diagnosed as having stomach cancer. He died one year later. Calculated from the heavy fallout year of 1953, the latent period for

his cancer would be 17 years, which is consistent with the BEIR-III Committee's estimate of 14+ years based upon data from Hiroshima. See BEIR-III Report DX-1025, at 364. The Johnson survey reports a statistically significant increase of stomach cancer among Mormon women in southern Utah for the period 1958-1966 (6 observed/0.6 expected, $p = 0.01$) but no material increase in incidence is reported among men (3 observed/1.7 expected [1958-1966]; 3 observed/2 expected [1972-1975] or among both sexes in the 1972-1980 period (5 observed/2.8 expected). While a significant increase of stomach cancer incidence has been observed in Carbon County, Utah, see J. Dixon, M.D., et al., "Cancer of the Stomach in Utah—An Analysis of 637 cases" (1970), DX-799, this may be related to coal mining, see Tr. at 5223 (testimony of Dr. Cecelia Fenoglio); the available Utah Cancer Registry Statistics identify no similar increase in Parowan, Utah or its environs. The correlation between stomach cancer and dietary factors, see id. at 5224, and the increased incidence of stomach cancer in exposed groups among older rather than younger persons also weighs against the drawing of an affirmative inference.[191] The slightly greater distance of Parowan, Utah from the NTS would put Melvin Orton's home a few miles out of the direct path of several of the more serious fallout events, see e.g., ORERP maps, DX-1118, but still well within a geographical proximity that could rationally connect conduct with injury.

Though several factual connections weigh strongly in the plaintiff's favor in this case, the absence of identifiable statistical evidence of augmentation tips the scales against the plaintiffs, even if the fairly strong rebuttal testimony is ignored entirely. While exposure to fallout may well have been a factor contributing to Melvin Orton's cancer, the evidence in the record does not demonstrate it to be a legally "substantial" one.

(13.) GLEN S. HUNT

Born in 1920, Glen S. Hunt lived in Hatch or Cedar City, Utah between 1951 and 1959. He was diagnosed in August of 1978 as having adenocarcioma of the pancreas. He died in 1980.

While cancer of the pancreas has been tentatively related to

radiation exposure by studies of human data in Japan and in follow-up studies of high-dose medical irradiation, the BEIR-III Committee reports that "[t]he risk of pancreatic cancer at moderate radiation doses was difficult to assess, although it seems likely that it was relatively low, for example, relative to the risk of leukemia induced under the same conditions of irradiation." BEIR-III Report, DX-1025, at 385. The limited data connecting radiation and pancreatic malignancy is overwhelmed by that identifying cigarette smoking as the leading cause of that form of cancer. Ingestion of coffee and various organic chemicals has been strongly identified with pancreatic cancer in laboratory animals and in some human studies. Tr. at 6139-41 (testimony of Dr. Phillip Schein). A review of the record concerning Glen Hunt discloses that he was a regular cigarette smoker, using between 1.5 and 2 packs of cigarettes per day, Tr. at 1872, and that he drank coffee. Particularly in the absence of increased incidence of pancreatic cancer among Mormons—or anyone—in southern Utah that could logically be identified to fallout exposure, the significance of tobacco as a contributing factor appears overwhelming. The evidence in the record clearly preponderates against fallout radiation as a substantial factor contributing to Glen Hunt's injury and death.

The case of Glen Hunt, however, presents an opportunity for a comment or two concerning the inherent weaknesses in the dose reconstruction evidence offered by the Government. For example, the ORERP calculations suggest dosimetry for various of Glen Hunt's organs resulting from fallout contamination from shot HARRY as follows:

GLEN HUNT

SHOT NAME IS HARRY

DOSE IN RAD

NUCLIDE	PANCREAS	LIVER	LUNGS	OVARIES	R MARROW	TESTES	THYROID	TOT BODY	UTERUS
NP239	2.80E-05	7.25E-05	3.57E-06	2.12E-04	7.49E-05	1.72E-05	3.71E-07	7.39E-05	8.94E-05
SR 89	1.20E-04	1.20E-04	1.20E-04	1.20E-04	1.71E-03	1.20E-04	1.20E-04	3.64E-04	1.20E-04
SR 90	2.20E-05	2.20E-05	2.20E-05	2.20E-05	1.77E-03	2.20E-05	2.20E-05	5.60E-04	2.20E-05
SR 91	8.65E-06	6.33E-06	3.56E-06	2.45E-05	1.26E-05	4.53E-06	2.81E-06	1.68E-05	1.41E-05
Y 93	8.20E-07	0	0	0	0	0	0	0	0
ZR 97	1.25E-05	9.30E-06	2.05E-06	7.25E-05	1.52E-05	6.09E-06	3.10E-07	2.27E-05	3.31E-05
MO 99	8.92E-05	1.01E-03	7.32E-05	8.39E-05	2.02E-04	6.49E-05	6.22E-05	1.02E-04	7.70E-05
RU 103	2.65E-05	2.32E-05	1.51E-05	1.19E-04	3.44E-05	2.52E-05	1.29E-05	3.71E-05	5.51E-05
RH105	7.99E-07	7.59E-07	1.09E-07	4.94E-06	1.29E-06	6.55E-07	2.94E-07	2.32E-06	2.16E-06
RU 106	7.30E-05	7.25E-05	7.14E-05	8.25E-05	7.34E-05	7.30E-05	7.10E-05	1.01E-04	7.64E-05

DOSE IN RAD

NUCLIDE	PANCREAS	LIVER	LUNGS	OVARIES	R MARROW	TESTES	THYROID	TOT BODY	UTERUS
I131	9.85E-05	8.14E-05	1.68E-04	6.72E-05	1.55E-04	6.18E-05	6.09E-01	4.25E-04	7.07E-05
TE131	1.29E-04	1.27E-04	1.15E-04	1.80E-04	1.54E-04	1.26E-04	2.07E-02	1.15E-04	1.61E-04
I133	8.62E-05	6.07E-05	7.03E-05	5.52E-05	6.65E-05	5.61E-05	1.41E-01	1.15E-04	5.80E-05
I135	1.81E-05	9.11E-06	8.98E-06	8.65E-06	8.72E-06	7.62E-06	4.28E-03	1.20E-05	9.17E-06
CS136	5.74E-05	5.89E-05	4.88E-05	5.74E-05	5.49E-05	5.64E-05	5.08E-05	4.79E-05	7.15E-05
CS137	1.26E-03	1.28E-03	1.19E-03	1.21E-03	1.24E-03	1.31E-03	1.26E-03	1.32E-03	1.35E-03
BA140	6.67E-05	4.21E-05	1.75E-05	3.43E-04	1.23E-04	6.49E-05	3.63E-05	1.02E-04	1.66E-04
CE143	4.58E-06	3.36E-06	5.87E-07	3.27E-05	7.83E-06	2.36E-06	6.71E-08	3.79E-05	1.32E-05
CE144	6.86E-07	3.65E-05	3.44E-07	3.68E-06	4.70E-06	5.37E-07	2.72E-07	4.28E-05	1.63E-06
ND147	1.23E-06	3.01E-06	4.72E-07	3.51E-05	9.58E-06	2.66E-06	5.18E-08	1.42E-05	1.34E-05
TOTAL	2.10E-03	3.04E-03	1.93E-03	2.74E-03	5.72E-03	2.02E-03	7.77E-01	3.51E-03	2.41E-03

There are at least two aspects of this evidence which can be misleading: (1) the use of "significant" figures, e.g., a strontium-90 dose to the pancreas of 2.20×10^{-5} rads, not 2.22 or 2.18, or some different amount; the precision of the stated figure is betrayed by its potential inaccuracy. The potential error in the stated figure compared to whatever actual dose was received is far greater than the figure itself. The real amount may vary by a factor of 2, 5, 10, 100 or more, depending on real, unreconstructable events. The difference between precise calculations and demonstrably accurate ones is a critical distinction; (2) Glen Hunt, like almost all men, had neither ovaries nor a uterus.

The ORERP calculations of radiation dose to any of the plaintiffs represents the sum total of thousands of such precisely ciphered, error-laden uncertainties. Use of the omniscient computer notwithstanding, the ORERP dose estimates, like any other estimates offered in this case, are no stronger than a well-educated guess.

(14.) KARLENE HAFEN

Karlene Hafen was born on August 4, 1941. She spent her entire life in St. George, Utah. When atmospheric testing in Nevada began, she was 9 years old. She was diagnosed as having acute myelogenous leukemia in February of 1956, at the age of 14. She died 9 months later. Tr. at 1759-1781.

(15.) SYBIL D. JOHNSON

Sybil Johnson was born on November 6, 1952 and spent her life in Cedar City, Utah. At the age of 11, in May of 1964, she was

diagnosed as having acute lymphoblastic leukemia. She died a year later, on May 15, 1965. The probability of pre-natal in utero exposure to fallout radiation is apparent from the face of the record, particularly where exposure in the first trimester is concerned. At the time of the heavier fallout from the 7 tower shots and 4 air bursts of UPSHOT/KNOTHOLE (1953), she was 5-7 months old. Tr. at 1782-98.

(16.) SHELDON NISSON

Sheldon Nisson was born on June 17, 1946 and lived in Washington, a small community near St. George, Utah. In March of 1959, at the age of 12, he was diagnosed as having acute myelogenous leukemia. He died 4 months later. Tr. Vol. III, pp. 7 et seq. At the commencement of NTS atmospheric testing, Sheldon Nisson was 4 years old. The heavy fallout series, UPSHOT/KNOTHOLE, had concluded only two weeks before his seventh birthday. Six years later, his leukemia was diagnosed. His home community, according to ORERP fallout maps, lay directly in the path of heavy fallout from shots HARRY and ANNIE in 1953, see id. DX-1118, nos. 3, 4, 5 & 13. Other tests likely contributed additional exposures.

(17). PEGGY L. ORTON

Peggy Orton, born January 12, 1946, was 5 years old when testing began with Operation RANGER at NTS in 1951. She lived in Parowan, Utah. On November 11, 1959, at the age of 13, Peggy Orton was diagnosed as having acute lymphoblastic leukemia. She died six months later, on May 29, 1960.

The causal relationship between the various forms of leukemia (except chronic lymphatic leukemia) and exposure to ionizing radiation is long and firmly established. See e.g., UNSCEAR Report (1977), PX-706/DX-605, ¶ ¶ 63-96 at 370-77; BEIR-III Report, DX-1025 at 331-57; Ulrich, "The Incidence of Leukemia in Radiologists," 234 New Eng. J. Med. 454-146 (Jan. 1946), PX-634; Maloney, "Leukemia in Survivors of Atomic Bombing," 253 New Eng. J. Med. 88 (July 21, 1955), PX-327; Lewis, "Leukemia and Ionizing Radiation," 125 Science 965 (May 17, 1951) PX-325, 668;

Furth & Upton, Leukemogenesis by Ionizing Radiation," Acta Radiological, Supplementum 116 (1954), DX-996; Saenger, et al., "Incidence of Leukemia Following Treatment of Hyperthyroidism," 205 J. Am. Med. Assoc. 147 (Sept. 1968), DX-1177; March, "Leukemia in Radiologists in a 20 Year Period," (undated), PX-326; Brass & Natarajan, "Leukemia from Low-Level Radiation," 287 New Eng. J. Med. 103 (July 20, 1972), PX-298; Upton, "The Biological Effects of Low-Level Ionizing Radiation," 246 Scientific American 41 (Feb. 1982), DX-1142; see also Martland, "The Occurrence of Malignancy in Radioactive Persons," 15 Am. J. Cancer 2435 (Oct. 1931), PX-868; Heyssel, et al., "Leukemia in Hiroshima Atomic Bomb Survivors," 15 Blood 313 (1960) PX-328; Bizzozero, "Radiation-Related Leukemia in Hiroshima and Nagasaki: 1946-1964. . . ," 274 New Eng. J. Med. 1095 (May 19, 1966) PX-329. All acute forms of leukemia predominate among those identified with a radiation etiology. UNSCEAR Report, supra ¶ 91 at 376. Analysis of the human data, particularly from the Japanese atomic bomb survivors, indicates a higher degree of risk among persons younger than 10 years at the time of exposure, and a notably shorter latency period.

Statistical excesses of acute leukemia in the exposed populations become apparent much sooner than for other cancers, often as early as 3 to 5 years following exposure. The common latency period for observed acute leukemia ranges between 8 and 13 years from exposure, with shorter latency periods identified for persons exposed at a younger age, or following prenatal exposure. See e.g., UNSCEAR Report, supra, 90-93, at 376. The radiation related excess of leukemia begin to decline within 15 years of exposure, but has remained detectable for 25 years. BEIR-III Report, supra at 332. Working from the exposure data for the Japanese survivors, the BEIR-III Committee observes, "the rate of increase in the 0-9 age group from 1950-1954 [5-9 years after exposure] exceeded that experienced by any other group. Cases in the youngest people tended to occur in the earliest years [before 1957], whereas the incidence in older survivors increased more gradually." Id. DX-1025, at 336, accord, Hiroshima and Nagasaki, supra, at 259-69.

Careful review of the testimony and exhibits concerning studies of populations in the off-site area undertaken by Weiss,[192] Heath[193] and Lyon[194] disclose substantial evidence of increased incidence of leukemia, particularly among children. Dr. Joseph L. Lyon testified that in his opinion, the data reflects a probability between 59 and 71 percent that the leukemia resulted from exposure to fallout radiation. Tr. at 729-32. Heath and Weiss identified a two-to-twenty-fold increase in incidence rates in some off-site communities. See Tr. at 529, 540, 552; id., 502-607 (testimony of Clark W. Heath, Jr.). Lyon described a 240 to 340 percent incidence in childhood leukemia in Utah counties closest to the identified patterns of significant fallout when compared to expected rates. Tr. at 647, 676. The existence of a significant excess of leukemia cases in southern Utah is further buttressed by the Johnson survey which reports a statistically significant increase in leukemia among southern Utah Mormons: (19 observed/3.6 expected [p = 0.01] for 1958-1966; 12 observed/3.4 expected [p = 0.01] for 1972-1980) with a higher excess number of leukemia cases among men (e.g., 12 observed./2.6 expected for males compared to 7 observed/1.1 expected for females 1958-1966); a greater incidence was noted among men in the Japanese data. See BEIR-III Report, supra, DX-1025, at 338, 342 (table).

The factors of age, apparent latency period,[195] type of leukemia, proximity to NTS fallout patterns, when added to the persuasive statistical evidence in the record justifies the rational inference that exposure to fallout radiation was a substantial factor contributing to the incidence of leukemia in each of the four cases listed above.

The rebuttal testimony, evidence and studies submitted by the Government[196] point up a number of practical problems faced in doing population studies where population is comparatively sparse; the alternative explanations relating to random chance, possible under diagnosis of leukemia prior to 1951, companion to distant "control" populations, etc. are also of some moment. These arguments, even if combined with speculations concerning family history, dosimetry or dose-response relationship, fail

to effectively refute the substantial basis for the inference already drawn.[197]

(18.) ARTHUR R. BRUHN

Arthur Frederick Bruhn, a resident of St. George, Utah from 1951 through 1962, was born on September 30, 1916. He was 34 years old when atmospheric testing began at NTS. He was diagnosed in December of 1963 as having acute lymphoblastic leukemia. He died seven months later. Testimony indicates that he may have been exposed to significant fallout radiation from shot HARRY in 1953 following observation of the shot from a hillside west of St. George. See Tr. at 5746-48 (testimony of Richard Smale); id. Vol. I at 36-63 (testimony of JoAnn Workman).

(19.) JOHN E. CRABTREE

John Edward Crabtree was born on September 13, 1912. He lived in Cedar City, Utah, working as a traveling salesman until his death on January 25, 1966. In June of 1964, at the age of 51, he had been diagnosed as having acute myeloblastic leukemia.

(20.) LENN McKINNEY

A resident of Fredonia, Arizona, Lenn McKinney was born on December 1, 1918. He was diagnosed as having leukemia in June of 1961, though the specific type was in dispute at trial. He died on May 14, 1962. Dr. Clark Heath identified a "cluster" of leukemia in Fredonia, Arizona which appeared between 1960 and 1964 with an observed incidence exceeding that expected for the community by a factor of twenty. Tr. at 529. Eight years prior to detection of Lenn McKinney's illness, Fredonia had been in the direct path of significant fallout from shot SIMON (April 25, 1953) as well as being in close proximity to that from other shots. See e.g., ORERP fallout maps, DX-1118, map 7.

(21.) LAVIER C. TAIT

Lavier C. Tait was born on April 5, 1928. He was 22 years old when atmospheric nuclear testing began in Nevada. He resided in

Orderville and Mt. Carmel, Utah, and Fredonia, Arizona until his death on September 13, 1965, at the age of 37. He was diagnosed in August 1964 as having chronic myeloytic leukemia.

While the relative sensitivity of the adult leukemia victims is indicated to be considerably lower than that of the younger children, the observed increase in leukemia incidence remains, particularly in relation to the Fredonia, Arizona cases. Increased potential for direct exposure to fallout in the case of Arthur Bruhn adds a factor in addition to the statistical evidence available, for example, from the Johnson survey. The latency periods in each case are wholly consistent with radiation etiology if calculated from the 1953 higher fallout series, UPSHOT/KNOTHOLE. The evidence in the record reasonably justifies the inference that it is more likely than not that fallout radiation was a substantial factor contributing to the leukemia identified in each case.[198] A preponderance of the evidence so indicates; the inference is not overcome by the rebuttal testimony offered.

(22.) DAISY L. PRINCE

Daisy Lou Prince was born on May 3, 1932. She resided in Cedar City, Utah from 1952 through 1959. In November of 1977 she was diagnosed as having histiocytic lymphoma. Nine months later, she died. Calculated from 1953 the apparent latency period of her cancer would be 24 years.

Analysis of the Japanese-data relating to malignant lymphoma indicates an increased risk of lymphoma in persons under 25 years of age at the time of exposure. See Hiroshima and Nagasaki, supra, at 273; but see BEIR-III Report, DX-1025 at 351. The data also indicates a latency period of at least 15 years, with a less pronounced excess incidence than that observed for leukemia. Id.

While statistical evidence of increase in lymphoma is notably less striking than that for leukemia, the data reported by the Johnson survey indicates a statistically significant increase in lymphatic cancer among women in selected communities for the period 1972-1980. (6 observed/1.9 expected [$p = 0.05$], but not earlier, nor among men at all during the studied periods.

While a causal relationship between radiation and Daisy Prince's cancer is plainly a possibility,[199] the evidence in the record fails to establish that fallout exposure was more likely than not a legally "substantial" factor contributing to her illness.

(23.) NORMA J. POLLITT

Norma Jean Benson Pollitt was born on December 31, 1941. During the period of atmospheric nuclear testing in Nevada, she was 9-16 years old and resided in Cedar City, Utah. On December 29, 1978, at the age of 36, she was diagnosed as having adenocarcinoma of the breast. Calculated from 1953, ostensibly the year of heaviest off-site fallout, her apparent latency period was 25 years. She died in August of 1983.

The human data and literature concerning radiation-induced breast cancer are extensive. The conclusion consistently reached in the literature is that "[t]he female breast is one of the organs most susceptible to radiation carcinogenesis." BIER-III Report, DX-1025, at 269; accord, UNSCEAR Report (1977), PX-706/DX-605, 189 at 393 ("[I]t is clear that breast cancer may be induced with relatively high frequency by radiation, particularly in adolescence and early adult life."); Hiroshima and Nagasaki, supra, at 297 ("[O]ne can safely assume an evident correlation between [radiation] exposure and breast cancer."). It is also consistently reported that young women in the 10-19 year age group are placed at significantly greater risk than are women in older groups. BEIR-III Report, supra, at 138, 175, 269 ff; UNSCEAR Report, supra, ¶ 160 at 389, ¶ 199 at 394; Hiroshima and Nagasaki, supra, at 295-296:

> Results showing that the young are much more susceptible to radiation than are the old have been obtained from the higher incidence of breast cancer in those exposed at a young age (ten to nineteen years). These results suggest the necessity of considering age and endocrinological conditions accompanying age in breast cancers from exposure to the atomic bomb.,

Cf. J. Gofman, Radiation and Human Health 234-265 (1981), PX-1046. The latency period in the case of Norma Pollitt is consistent with that observed for her age group among the Japanese, Hiroshima and Nagasaki, supra at 295 ("[I]n the exposed women of this group [between the ages of 10 and 19], the total of breast cancer cases occurring twenty-four years after exposure is almost equal to the whole-life expected number."), and other groups studied. See UNSCEAR Report, supra ¶ 180 at 392 ("over 80 percent of the total number of [breast] cancers induced would be diagnosed only after 20 years following exposure."); id. ¶ 187 at 392 ("[T]he mean latency from irradiation to diagnosis was 23.6 years."); id. ¶ 189 at 393:

> Cases start to appear in excess of normal expectation within 10 years of irradiation, and new cases continue to appear for over 30 years more, the mean latency probably being in the region of 25 years.

The data reported by the Johnson survey are consistent with this latency pattern and indicate a statistically significant [p = 0.01] increase among women 14 years or more following exposure:

1958-1966	8 observed	8.8 expected
1972-1980	27 observed	14.2 expected

The evident consistency of Norma Pollitt's injury with the probability of radiation induction, strongly indicated by the significant age-sensitivity, latency period and statistical factors,[200] preponderates heavily in favor of an inference that exposure to fallout radiation was a substantial factor contributing to her injury. That inference is insufficiently rebutted by weak dose estimation and testimony suggesting alternative factors of less apparent significance.[201]

(24.) JACQUELINE SANDERS

Jacqueline Sanders was born on November 3, 1945. She was 5 years old when nuclear testing began near her home in St. George.

Utah. On March 20, 1967, at the age of 21, she was diagnosed as having adenocarcinoma of the thyroid.

Like that pertaining to breast cancer or leukemia, the human data and scientific literature concerning radiation-induced thyroid cancer is extensive.[202] The evidence now available indicates the thyroid to be an organ of high sensitivity for radiation carcinogenesis.

> In summary, therefore, it is evident that thyroid cancers are induced by radiation at absorbed doses at over 100 rad and probably even at less than 10 rads. The induction rate per unit absorbed dose appears to be somewhat higher in females than in males, and is probably also rather higher in infants and children than in adults.. . .

UNSCEAR Report (1977), PX-706/DX-605 ¶ 142 at 383. The latency period for development of thyroid cancers on the average appears to range between 9 and 20 years, or more depending on the study. Id., ¶ ¶ 97-150 at 377-385; BEIR-III Report, (1980), DX-1025 at 304 ("A minimal latent period of 10 yr seems to be reasonable, paralleling other radiation-induced solid tumors. A peak incidence perhaps 20 year after exposure is suggested by some studies"). 3 additional thyroid cancers were observed among the Marshallese between 16 and 22 years following the 1954 irradiation. UNSCEAR Report, supra, ¶ 109 at 379.

While limited study of the incidence of thyroid abnormalities among southern Utah school children has been undertaken, see e.g. M. Rallison, M.D., et al., "Thyroid Disease in Children: A Survey of Subjects Potentially Exposed to Fallout Radiation," 56 Am. J. Medicine 457 (April 1974), DX-1027, the exposure follow-up was a maximum period of 18 years for children born between 1947 and 1953 studied in 1965-1968 and 18 years for children (high school seniors only) born between 1951 and 1953 and studied in 1969-1971. The Rallison study, for example, would miss entirely the case of Jacqueline Sanders, a child exposed to fallout throughout the 1951-1962 period, but who passed through the school system two years before the groups actually studied.

Dose estimates to thyroid tissue for southern Utah children have characteristically been higher than those for other organs, or whole-body estimates. See e.g. Rallison, supra, at 457; BEIR-III Report, supra, at 300 ("the estimated radiation dose, primarily from iodine-131, was approximately 120 rads to the exposed group. . . an average radiation dose of 18 rads quoted by the authors is misleading, in that it is based on the sum of the exposed and non-exposed populations. Radiation doses may actually have been higher, ranging from 30 to 240 rads (Mays, personal communication)."); Tr. at 2447-2669 (testimony of Dr. Harold A. Knapp); id., at 2471 ("[I]f you took. . . the Harry shot and the measurements of fallout that were recorded in St. George after that, the best estimate of the range of doses was between 120 rads to 440 rads."); Pendleton, et al., "Differential Accumulation of I131 from Local Fallout in People and Milk," 9 Health Physics 1257-1262 (1963), PX-32; Tamplin and Fisher, "Estimation of Dosage to Thyroids of Children in the U. S. from Nuclear Tests Conducted in Nevada During 1952 Through 1955," TID-4500, Lawrence Radiation Laboratory (May 10, 1966), PX-1004 (120 rads to thyroids of children in St. George; 50 rads estimated for children in Utah, Nevada area); see also Knapp, "Iodine-131 in Fresh Milk and Human Thyroids Following a Single Deposition of Nuclear Test Fallout," (June 1, 1963) PX-286; _____, "Average and Above Average Doses to the Thyroids of Children in the United States from Radioiodine from Nuclear Weapons Tests," (Aug. 6, 1962) PX-281; _____, "Observed Relations Between the Deposition Level of Fresh Fission Products from Nevada Tests and the Resulting Levels of I-131 in Fresh Milk," (Mar. 1, 1963) PX-284; Memorandum, Mar. 21, 1963, PX-285.

Even the Off-Site Radiation Exposure Review Project, through the work of Anspaugh and others, estimates a dose to Jacqueline Sanders' thyroid due to fallout from 7 selected nuclear tests ranging from 29-31 rads to 340 rads, depending upon such unanswerables as how much milk she really drank as a child on a daily basis, and how much foliage really grew in dairy pastures in 1953. See Transcript of DAAG Meeting, July 22, 1981, Vol. I, DX-1014, at 299-307; id., at 321-330, 453 (tables); Transcript of Fifth DAAG Meeting, May 6, 1982, Vol. I, DX-1018, at 154. Gofman's theoreti-

cal dose calculation for Jacqueline Sanders' thyroid is 717.6 rads.[203]

The figures reported by the Johnson survey indicate a statistically significant increase of thyroid cancer, particularly among women:

Total thyroid	1958–1966	6 observed/1.4 expected [p = 0.01]
cancer	1972–1980	14 observed/1.7 expected [p = 0.01]
Women	1958–1966	6 observed/1.0 expected [p = 0.01]
———	1972–1980	9 observed/1.3 expected [p = 0.01]
Men	1958–1966	0 observed/...expected
———	1972–1975	5 observed/0.4 expected [p = 0.01]

The ambiguity of statistical evidence relating to thyroid abnormalities and cancers in southern Utah reflects the dire importance of much more thorough studies and more complete periods of follow-up examination for all groups of persons potentially exposed to significant fallout contamination. Recurring estimates of absorbed dose to the thyroids of children in southern Utah—and specifically in the case of Jacqueline Sanders—in the range of 100 rads or greater (compared, for example, to Glen Hunt's ORERP estimate of 0.42 rads to his pancreas) combined with consistent latency and statistical factors, points unmistakably to the conclusion that exposure to fallout radiation was more likely than not a substantial factor contributing to Jacqueline Sanders' cancer. In this case, the Government's own "ball park" estimates of a thyroid dose of 30-340 rads combined with similar estimates from other sources is the strongest single factor justifying that inference. Testimony offered in rebuttal, based only on the lowest of the reasonable ORERP estimates, fails to meet the issue.[204]

X. DAMAGES

After careful examination of the factors discussed in detail

above in all of the preceding sections, it appears that ten of the twenty-four bellwether cases merit compensation. Eight are wrongful death cases, 2 in Arizona and 6 in Utah. Heirs or survivors seek compensation for themselves for the wrongful deaths of their predecessors.

The two additional cases which merit compensation are brought by persons living at the time the action was commenced who claim personal injury to themselves. Norma Jean Pollitt has since died. Because her death modifies the amount of damages which the defendant is obligated to pay, no effort at this time is made to fix an amount awaiting record supplementation. See page 416.

The six Utah death cases and the two Utah personal injury cases are governed by Utah law as to the quantum of compensation. The two Arizona death cases are governed by Arizona law as to the quantum of compensation.

Two Utah statutes provide for wrongful death actions in Utah. Section 78-11-6 establishes a cause of action for parents or guardians of a deceased child. It provides that:

> [A] parent or guardian may maintain an action for the death or injury of a minor child when such injury or death is caused by the wrongful act or neglect of another. Any such action may be maintained against the person causing the injury or death, or, if such person is employed by another person who is responsible for that person's conduct, also against such other person.

UTAH CODE ANN. § 78-11-6 (1977). Section 78-11-7 establishes a similar cause of action for the heirs and representatives of deceased adults. It provides that:

> [W]hen the death of a person not a minor is caused by the wrongful act or neglect of another, his heirs, or his personal representatives for the benefit of his heirs, may maintain an action for damages against the person causing the death, or if such person is employed by another person who is responsible for his conduct, then also against such other person.

Id. § 78-11-7 (1977).

The Utah wrongful death statute has carried identical language relating to damages throughout its history. Compare Laws of the Territory of Utah, Title III, § 234, 1884 Laws of Utah 94 ("In every action under this and the preceding section, such damages may be given as under all the circumstances of the case may be just.") with UTAH CODE ANN. § 78-11-7 (1977) ("In every action under this and the next preceding section [78-11-6] such damages may be given as under all circumstances of the case may be just.").

For nearly a century, the Utah Supreme Court has discussed the scope of damages in wrongful death cases. In Beaman v. Martha Washington Mining Company, 23 Utah 139, 63 P. 631 (1901), a case involving the wrongful death of a child, the supreme court upheld a jury instruction that directed the jury as follows:

> In determining the amount of damages, you may take into consideration the age, mental and physical health at the time of his death, his probable length of life, his ability and disposition to labor, his habits of living, the probable earnings of the deceased before coming of age, from which should be deducted the reasonable cost of his care and maintenance during his minority; also, the loss of comfort, society and companionship of said deceased, if any, that the plaintiff has sustained by his death, and the amount, if any, expended for funeral expenses

Id. 63 P. at 632. The Beaman court also confirmed that "damages could not be awarded on account of any loss to the deceased child, or suffering on his part." Id. at 633; accord, Corbett v. Oregon Short Line Railway Company, 25 Utah 449, 455, 71 P. 1065, 1067 (1903).

Other early Utah Supreme Court decisions upheld cases applying similar criteria in wrongful death cases where the decedent was an adult. In Spiking v. Consolidated Railway & Power Company, 33 Utah 313, 93 P. 838 (1908), the supreme court stated:

> Under our statute, both the wife and the children were heirs

> of the deceased, and as such were entitled to recover, not only for the loss of support, companionship and assistance he would naturally and probably be to them, but were entitled to all the pecuniary loss that they may have sustained by reason of his death, which could be established with reasonable certainty. . . .

Id. 93 P. at 847. See Evans v. Oregon Short Line Railway Company, 37 Utah 431, 108 P. 638 (1910). Some Utah cases allowed juries to consider the probability of the deceased acquiring an estate that the minor child would inherit as an element of compensatory pecuniary damages. Parker v. Bamberger, 100 Utah 361, 116 P.2d 425 (1941); Burbidge v. Utah Light & Traction Company, 57 Utah 566, 196 P. 556 (1921).

Recent Utah Supreme Court decisions have re-affirmed these historical interpretations of the Utah wrongful death statutes. In In re Behm's Estate, 117 Utah 151, 213 P.2d 657 (1950), the supreme court enumerated the elements of damages in an adult wrongful death case:

> Besides the financial support furnished by deceased to his or her family, the loss of deceased's care and solicitude for the welfare of his or her family and the loss of the comfort and pleasure the family of the deceased would have received are all matters to be considered in assessing damages. . . .

Id. 213 P.2d at 661. Most recently, in Switzer v. Reynolds, 606 P.2d 244 (Utah 1980), the supreme court stated that in an action alleging wrongful death "the full value of the life of the deceased is determined and recovered" and highlighted the following elements as important in assessing recoverable damages: "financial support furnished; loss of affection, counsel and advice; loss of deceased's care and solicitude for the welfare of the family; and loss of the comfort and pleasure the family of the deceased would have received." Id. at 246.

In Jones v. Carvell, 632 P.2d 105 (Utah 1982), the Utah Supreme Court reiterated the elements of damages for the wrongful death of a child. According to the court:

> Under Utah law a parent may recover for the wrongful death of a child such damages as funeral and medical expenses, the value of the services he might have rendered to the household, and the amount of money the deceased child might have earned, if its projected income would have exceeded the cost of its maintenance and care. However, damages are not limited to such losses and this jurisdiction has emphasized from the beginning that the greatest losses arising from the wrongful death of a child are not those losses which are economic in nature. It is the loss of society, love, companionship, protection and affection which usually consitute the heart of the action.

Id. at 108.

In summary, it appears that four elements are ordinarily considered in determining compensation to survivors in wrongful death actions in Utah: 1) loss of support; 2) loss of assistance and service to the family; 3) loss of society, companionship and happiness of associations; and 4) loss of the possibility of inheritance, if the decedent is an adult. See, Platis v. United States, 288 F. Supp. 254, 275 (D.Utah 1968) affirmed 409 F.2d 1009 (10th Cir. 1969).

The Utah law concerning damages for personal injury is also clear. Utah allows injured plaintiffs to recover general and special damages that naturally and necessarily result from the harm done, including damages for loss of time and earnings, impairment of future earning capacity, expenses of drugs, nursing and medical care, pain and suffering, and aggravation of a pre-existing disease by the injury, if properly pleaded. See, e.g., Cohn v. J. C. Penney Company, Inc., 537 P.2d 306 (Utah 1975); Jorgensen v. Gonzales, 14 Utah 2d 330, 383 P.2d 934 (1963).

Arizona statutes also establish a cause of action for wrongful death. Section 12-611 provides that:

> [W]hen death of a person is caused by wrongful act, neglect or default, and the act, neglect or default is such as would, if death had not ensued, have entitled the party injured to

> maintain an action to recover damages in respect thereof, then, and in every such case, the person who or the corporation which would have been liable if death had not ensued shall be liable to an action for damages, notwithstanding the death of the person injured, ...

ARIZ. REV. STAT. ANN. § 12-611 (1982). Section 12-612 provides that the spouse, children, parents or estate of the deceased may recover in an action for wrongful death. Id. § 12-612 (1982). The amount of damages recoverable in a wrongful death action is discussed in section 12-613, which states:

> [I]n an action for wrongful death, the jury shall give such damages as it deems fair and just with reference to the injury resulting from the death to the surviving parties who may be entitled to recover and also having regard to the mitigating or aggravating circumstances attending the wrongful act, neglect or default.

ARIZ. REV. STAT. ANN. § 12-613 (1982).

While Arizona has traditionally recognized that pecuniary damages may be recovered in wrongful death actions, Calument & Arizona Mining Company v. Gardner, 21 Ariz. 206, 187 P. 563 (1920), more recent Arizona decisions have expanded the elements to be considered in granting damages for wrongful death. In Salinas v. Kahn, 2 Ariz. App. 181, 407 P.2d 120 (1965) modified 2 Ariz. App. 348, 409 P.2d 64 (1965), the Arizona Court of Appeals held that damages could be recovered for loss of probability of inheritance in a wrongful death suit. Id. at 134. In Boies v. Cole, 99 Ariz. 198, 407 P.2d 917 (1965), the Arizona Supreme court described compensation under the wrongful death statutes as being "measured by the injury to the surviving parties" and stated "[t]he measure of damages is no longer limited to pecuniary damages, but also includes allowance for such things as loss of companionship, comfort and guidance." Id. at 920. These principles were expanded upon in City of Tucson v. Wondergem, 105 Ariz. 429, 466 P.2d 383 (1970), where the Arizona Supreme Court stated:

> [T]here can be little argument against allowing damages 'resulting from the death' for 'anguish, sorrow, stress, mental suffering, pain and shock,'. . . where we have held. . . that damages for loss of companionship, comfort and guidance are recoverable. The loss of companionship and comfort certainly results in sorrow, and the failure to permit such recovery falls short of 'fair and just' standards set forth in § 12-613, A.R.S.

Id. at 387. Accord, Southern Pacific Transportation Company v. Lueck, 111 Ariz. 560, 535 P.2d 599 (1975), after remand, 112 Ariz. 277, 540 P.2d 1258 cert. den. 425 U.S. 913 (1976).

It appears, then, that the Arizona courts recognize many of the same damage elements as do the Utah courts. Pecuniary damages to compensate for loss of support, damages for the loss of companionship, comfort and guidance of the deceased, and damages for the loss of probability of inheritance are all recoverable in wrongful death cases in Arizona.

There is no genuine monetary compensation for the loss of a child. The law says in dollars what no one can ever say in dollars. The intangible loss—society, companionship, association—is obviously the greatest of the losses.

For the loss of a husband and father, the pecuniary injury is more readily apparent, although there is of course the loss of nurture and guidance for a child left behind, and the loss of society and companionship for a spouse left behind.

Plaintiffs seek on behalf of those who survive, an award of compensation for the pain and suffering of those who are dead (Pltff's Trial Brief-Re: Damages.). They misread. Those who survive are not so entitled and no sum has been awarded based on that theory.

Plaintiffs who have represented others entitled to compensation have asked that the court apportion the overall sum awarded among those said to be entitled to share therein. To the extent information has been provided as part of the record, the court has

endeavored to comply with the request. In reality this is merely a determination of the individual losses. The overall sum is merely the sum of such losses.

The court finds in the following cases that the claimants indicated have been damaged by the wrongful death of the deceased person indicated in the sums indicated:

Deceased	Claimant	Status	Amount
ARTHUR F. BRUHN	Lorna C. Bruhn	Spouse	$400,000
	Michael F. Bruhn	Child(M)	150,000
	Eleanor K. McDonald	Child(A)	75,000
JOHN E. CRABTREE	Florence M. Crabtree	Spouse	125,000
	Wendy C. Snipe	Child(M)	25,000
	Glenna C. Giddens	Child(M)	25,000
	Joyce C. Messer	Child(A)	15,000
	Phyllis C. Gillins	Child(A)	15,000
	John A. Crabtree	Child(A)	15,000
	Carroll J. Smith	Child(A)	15,000
KARLENE HAFEN	Leora Hafen	Parent	250,000
SYBIL D. JOHNSON	Blaine Johnson	Parent	125,000
	Loah J. Johnson	Parent	125,000
LENN McKINNEY	Vonda McKinney	Spouse	200,000
	Donna McK. Patzke	Child(M)	50,000
	Stephen L. McKinney	Child(A)	25,000
	Arthur Y. McKinney	Child(A)	25,000
SHELDON D. NISSON	Darrell a. Nisson	Parent	250,000
PEGGY L. ORTON	Rula D. Orton	Parent	250,000
LaVIER TAIT	VaRene E. Tait	Spouse	240,000
	Nan T. Avent	Child(M)	40,000
	Teresa T. Hollenbeck	Child(M)	40,000
	Lindsey C. Tait	Child(M)	40,000
	Pattie T. Heaton	Child(M)	40,000

The court finds that the claimants indicated below have suffered damage in the sums indicated:

Claimant	Amount
NORMA JEAN POLLITT (now dead)	* * * (not yet fixed)
JACQUELINE M. SANDERS	$100,000

XI. FINDINGS OF ULTIMATE FACT

The court finds that defendant failed to adequately warn the plaintiffs or their predecessors of known or foreseeable long-range biological consequences to adults and to children from exposure to fallout radiation from open-air atomic testing and that such failure was negligent.

The court finds that defendant failed to measure adequately and concurrently with open-air atomic testing the actual fallout in communities and population centers near the Nevada Test Site on a person-specific basis, or its equivalent, and that such failure was negligent.

The court finds that contemporaneously with atmospheric atomic testing the defendant failed to adequately and continuously inform individuals and communities near the test site of well-known and inexpensive methods to prevent, minimize or mitigate the known or foreseeable long-range biological consequences of exposure to radioactive fallout, and that such failure was negligent.

The court finds that as a direct and proximate result of such negligent failures, individually and in combination, defendant unreasonably placed plaintiffs or their predecessors at risk of injury and as a direct and proximate result of such failures that each prevailing plaintiff designated in part X, beginning at page 415, suffered injury for which the sums set opposite their respective names should be paid.

CONCLUSIONS OF LAW

This opinion in its entirety shall constitute the Findings of Fact required by Rule 52 F.R.C.P. Based on the findings of specific and ultimate facts set forth above in this opinion and for the reasons set forth herein, the court concludes that each of the designated prevailing plaintiffs (claimants) named in Part X beginning at page 415 above is entitled to judgment against the United States in the amount set forth in that section. As to the remaining plaintiffs of the bellwether group of 24, this court concludes as a matter of law

that the evidence is insufficient in each instance to demonstrate with the requisite weight that the defendant's negligence proximately caused the condition of which each complains and further concludes that the United States is entitled to a Judgment of Dismissal as to each of them.

Since the legal questions dealt with in the 24 bellwether cases have significance to those cases individually and to the remaining cases affecting more than 1,100 plaintiffs, the court will certify in the judgments to be entered that each judgment shall be entered as final pursuant to Rule 54(b), terminating this action as to each plaintiff, and that an appeal shall be immediately available as to each of the plaintiffs in the 24 cases, there being no just cause or reason for delay.

In the event timely appeal is taken from such Judgment or judgments, this court will stay consideration of the remaining issues in the pending cases while awaiting the outcome of the appeal.

Attorneys for prevailing parties shall prepare and submit proposed judgments in accordance herewith and do so within twenty (20) days.

DATED this 9th day of May, 1984.

BY THE COURT:

(ORIGINAL SIGNED)

BRUCE S. JENKINS
United States District Judge

(THIS PAGE LEFT BLANK INTENTIONALLY)

FOOTNOTES

[1]While the presence of plaintiffs residing in other districts raises a potential question of venue, see 28 U.S.C. § 1402(b), the parties have agreed that if subject-matter jurisdiction exists, venue is not disputed. Pre-Trial Order at ¶ 1 (dated Sept. 13, 1982).

[2]While the court may in its discretion empanel an advisory jury, responsibility for making findings of fact and conclusions of law remains with the court. See e.g., Coffland v. United States, 57 F.R.D. 209 (N.D.W.Va. 1972).

[3]The trial transcript [hereinafter cited as "Tr."] extends to more than 7,000 pages. The exhibits now in evidence before this court amount to over 54,000 pages of written material contained in 19 cardboard boxes. Depositions filed with the court in this action fill an additional 5 boxes. In addition, the court has deemed additional material submitted by the parties to have been offered and received, e.g., S. Glasstone & P. Dolan, The Effects of Nuclear Weapons (3d ed. 1977), DX-12242, see Tr. at 3276. The court has also taken judicial notice of elementary principles of physics, chemistry, and other sciences, e.g., Handbook of Chemistry and Physics (64th ed. Weast 1983), see Part II, infra, of specific learned treatises, e.g., F. W. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment (1982) (2 vols.), and of government compilations of scientific and historical data, e.g., Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, Hiroshima and Nagasaki: The Physical, Medical, and Social Effects of the Atomic Bombings (Engl. trans. 1981), an official publication of the two cities. Rule 201(b)(2), Federal Rules of Evidence.

[4]See e.g., O. Frisch, Atomic Physics Today (1961); I. Asimov, Understanding Physics: The Electron, Proton, and Neutron (1966); S. Hecht, Explaining the Atom 3-94 (rev. ed. Rabinowitch 1954).

[5]See e.g., V. Weisskopf, "Atomic Structure and Quantum Theory," in The Mystery of Matter 95-120 (L. Young, ed. 1965);

T. Ashford, "Rutherford's Theory of the Nuclear Atom," in id., 84-94; R. Moore, Niels Bohr: The Man, His Science, and the World They Changed (1966).

[6]Consider, for example, Heisenberg's Uncertainty Principle, which is expressed in the following equation:

$$(\Delta p)(\Delta \chi) \approx h$$

Δp represents uncertainty of position
$\Delta \chi$ represents uncertainty of momentum
h Planck's constant
$\approx$ "Approximately equal to"

and which informs us that it is not possible to determine both the position and the momentum of a subatomic particle simultaneously and with unlimited accuracy. The closer we come to one value, the greater our uncertainty of the other. I. Asimov, Understanding Physics: The Electron, Proton, and Neutron 106-107 (1966).

[7]See generally, W. Bishin & C. Stone, Law, Language and Ethics (1972); B. Cardozo, The Nature of the Judicial Process (1921); R. Wasserstrom, The Judicial Decision (1961); L. Green, The Litigation Process in Tort Law (2d ed. 1977).

[8]In scientific notation, $10^{\circ} = 1$.

[9]The illustration is Planck's Constant expressed in joule seconds. Expressed in erg-seconds, the constant is 6.261965×10^{-27}. B. Taylor, W. Parker & D. Langenberg, 43 Rev. Mod. Phys. 375 (1969).

[10]Mathematicians sometimes venture beyond these limits for purely theoretical purposes, dealing in numbers as large as 10^{100} (popularly known as a "googol"), or $10(10^{100})$ (a/k/a "googolplex") or simple on to 00 (infinity). See generally, E. Kasner & J. Newman, Mathematics and the Imagination (1953). But even if measured in atomic mass units—a very, very small unit—the entire mass of all matter in the known universe amounts to less than 10^{80} amu—a mere one-hundred-quintillionth of a googol. See C. Sagan, Cosmos 219 (1980).

[11]McGraw-Hill Dictionary of Physics and Mathematics at A7 (Table 4) (Lapedes ed. 1978)

[12]The common measurement units of the explosive power of atomic or hydrogen bombs are the kiloton or megaton.

A kiloton is approximately the amount of energy that would be released by the explosion of 1,000 or 10^3 tons of trinitrotoluene, a high explosive. Similarly, a megaton represents the explosive power of 10^6 or 1,000,000 tons (10^3 or 1,000 kilotons) of TNT.

In energy units, a kiloton is equivalent to approximately 10^{12} calories, or 4.2×10^{19} ergs. A megaton approximates 10^{15} calories, or 4.2×10^{22} ergs. See S. Glasstone, The Effects of Nuclear Weapons 635,636 (3d ed. 1977).

In practical terms, all of the bombs dropped on all of the cities bombed in World War II represent an explosive power of nearly two megatons. See C. Sagan, Cosmos 320 (1980).

[13]In rough terms a curie represents the radioactivity of one gram of pure Radium-226, an important radioactive element. A megacurie of material would have the activity of 10^6 grams or 1,000 kilograms of pure Radium; a picocurie would have the activity of a millionth of a microcurie of pure Radium—quite a difference.

In more precise terms, a curie is an amount of radioactive material that is decaying at a rate of 3.700×10^{10} disintegrations per second. See S. Glasstone, Sourcebook on Atomic Energy ¶ 17.37 at 521n (2d ed. 1958).

[14]To say that atoms are very small is almost an understatement: the diameters of atoms (considered as spheres) generally range from 0.1 to 0.3 nm (i.e., 1×10^{-10} meters to 3×10^{-10} meters), or one to three ten-billionths of a meter. In a grain of sand, for example, one can easily fit 10^{18} atoms; a tablespoon of water holds 10^{22} atoms without spilling. See C. Yoder, et al., Chemistry 34 (2d ed. 1980).

[15]Mendelevium-256, one of the heaviest synthetic elements, has half-life of 1.5 hours, (meaning a sample of mendelevium-256 created first thing in the morning would be half gone in an hour-and-a-half, and would largely vanish by the end of the day, all but 1/64 of the sample having decayed into lighter elements.) Other synthetic elements persist for much longer periods: of an existing sample of plutonium-239, half would still exist 24,400 years from now. Plutonium-244 decays with a half-life of 8×10^7 years; curium-247 persists with a half-life of 1.6×10^7 years. See R. Heath, "Table of the Isotopes," in Handbook of Chemistry and Physics at B-541–B-561 (64th ed. Weast 1983).

[16]The mass of atoms and their component particles is often expressed in AMUs rather than grams. An approximate conversion factor is 1 AMU = 1.66×10^{-24} gm. Handbook of Chemistry and Physics at F-303 (64th ed. Weast 1983). The mass given in the text corresponds to a proton at rest, i.e., not one with a significant velocity.

[17]Each proton has a positive electrostatic charge of 4.80×10^{-10} absolute electrostatic units, equal to that of the electron, but of opposite sign.

[18]See H. Semat & J. Alright, Introduction to Atomic and Nuclear Physics 228 (5th ed. 1972). Underlying the text discussion is the deeply complex field of physics known as quantum mechanics. See e.g., id., at 153-308, 325-360; D. Livesay, Atomic and Nuclear Physics 172-271 (1966); L. Pauling & E. Wilson, Introduction to Quantum Mechanics (1935); J. von Neumann, The Mathematical Foundations of Quantum Mechanics (Beyer trans. 1955); M. Born, Atomic Physics (1959). For a simplified discussion of the central concepts, see H. Pagels, The Cosmic Code: Quantum Physics as the Language of Nature (1982); G. Zukav, The Dancing Wu Li Masters (1979).

[19]For example, an electron in an orbit having an energy of -1.36×10^{-12} ergs, may fall to an orbit having an energy of -2.41×10^{-12} ergs. The differences in energy, 1.05×10^{-12} ergs, is released in the form of a photon, a parcel of electromagnetic radiation, having the energy 1.05×10^{-12} ergs. To return to the higher orbit,

the electron must absorb 1.05×10^{-12} ergs of energy from some external source. C. Yoder, Chemistry 107 (2d ed. 1980).

[20]In conventional terms, momentum represents a quantity of motion determined by the product of the mass and velocity of an object or particle. For a relativistic particle, i.e., one moving at a velocity near the speed of light, momentum is determined by the formula:

$$\text{Momentum} = mv\,(1 - v^2/c^2)^{1/2}$$

where m is the rest mass of the particle, v the velocity and c the speed of light (2.998×10^{10} cm/sec). McGraw-Hill Dictionary of Physics and Mathematics 642 (Lapedes ed. 1978).

[21]These units are often referred to as quanta (singular, quantum) of energy. This quantum theory, as it is called, originated with the work of the German physicist Max Planck, ca. 1900. W. Michels et al., Foundations of Physics 363 (1968). Albert Einstein received the 1922 Nobel Prize in Physics for his theoretical expression which describes the interaction of light with matter in terms of discrete quanta of energy. See A. Pais, 'Subtle is the Lord. . . ': The Science of the Life of Albert Einstein 364-388 (1982).

[22]H. Becquerel, 122 Comptes Rendus 501, 689 (1896). As early as 1867, it was known that uranium salts could expose wrapped photographic plates, but the effect had always been ascribed to prior exposure of the salts to light. S. Glasstone, Sourcebook on Atomic Energy 53 n. (2d ed. 1858).

[23]While modern instrumentation is far more sophisticated and far more accurate, it represents in many cases a refinement of original technique. Film badges—photographic film wrapped in opaque paper—are currently used by health physicists to estimate with fair accuracy the radiation exposure of those who wear them. N. Tsoulfanidis, supra at 505; S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 8.26 at 331 (3rd ed. 1977), DX-1242; D. Halliday, Introductory Nuclear Physics 189-190 (1950); H. Yagoda, Radioactive Measurements with Nu-

clear Emulsions (1949); H. Yagoda, 2 Nucleonics 2 (May 1948). Film badges were available and were used at the Nevada Test Site in conjunction with nuclear testing. See Part VIII, infra.

Similarly, the pocket dosimeters in use at the time of the testing, as well as currently, are not different in principle from the original gold-leaf electroscopes used by Becquerel and Mme. Curie in the late 1890s. See S. Glasstone, Sourcebook on Atomic Energy 53, 143, 600 (2d ed. 1858); E. Pollard & W. Davidson, Applied Nuclear Physics 22-23 (1942).

[24]While at one time, gamma rays were thought to be distinguishable from x-rays by their higher energy, the more recent production of x-rays of equivalent energy has mitigated that difference. "The difference in nomenclature has, however, been preserved to indicate their origin: we call x-rays those originating from outside the nucleus, while by γ-rays [gamma rays] we mean rays coming from the nucleus." G. Jones, J. Rothblat, & G. Whitrow, Atoms and the Universe 31 (3d ed. 1973). Cr. Handbook of Chemistry and Physics F-86, F-110 (64th ed. Weast 1983).

[25]There is some evidence that in a fairly rare sort of spontaneous nuclear reaction known as an orbital electron capture, or K-capture (in which the nucleus captures one of its own orbiting electrons, reducing Z by 1), the chemical state of the atom has some impact. See S. Glasstone, Sourcebook on Atomic Energy 301 (2d ed. 1958). The far more common processes of α, β and γ emission, however, are not perceptably affected. Id. at 124.

[26]At this point, we know of no element with an atomic weight greater than 209 which can be described as "stable," i.e., exhibiting no radioactivity properties.

[27]The term "nuclide" refers to a species of atom characterized by the composition of its nucleus. A "radio nuclide" is a nuclide having observable radioactivity properties. See McGraw-Hill Dictionary of Physics and Mathematics 684-685 (Lapedes ed. 1978).

[28]See e.g., 1 E. Hyde, I. Perlman & G. Seaborg, The Nuclear Properties of the Heavy Elements: Systematics of Nuclear Structure and Radioactivity 211-302A (1971 ed.), and references cited therein; H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 440-442 (5th ed. 1972). Again the answer seems to be found in analyzing subatomic particles in terms of wave functions and probabilities.

[29]The probabilistic nature of nuclear physics is a product of analysis of matter in terms of quantum mechanics, a revolution in theoretical physics which has exploded in this century. See e.g., H. Pagels, The Cosmic Code: Quantum Physics as the Language of Nature 3-165 (pap. ed. 1982); A. Pais, 'Subtle is the Lord. . . ': The Science and the Life of Albert Einstein 55-110, 357-469 (1982).

[30]Unless otherwise specified, the data concerning half-life and the nature and energy of decay of the radioactive isotopes which are relied upon by this court are derived from this Table. This court takes judicial notice of this Table and of R. Heath, "Gamma Energies and Intensities of Radionuclides," a Table in the same Handbook, some edition, pages B-137 through B-335. See Rule 201, Federal Rules of Evidence.

[31]While ^{239}Pu is not a fission product, see Part III, infra it is still present, whether as unused fuel from a plutonium-based bomb, or as a product of the reaction between neutrons and uranium found somewhere in the bomb's structure, such as a reflector:

$$^{238}_{92}U + {}^{1}_{0}n \dashrightarrow {}^{239}_{92}U \dashrightarrow {}^{239}_{93}Np + \beta \dashrightarrow {}^{239}_{94}Pu + \beta \dashrightarrow$$

See N. Smith, Report of the Gabriel Project Study, Oak Ridge National Laboratory, at 9 (May 21, 1949) PX-679 ("[P]lutonium is present in the debris from all A-bombs, whether the original fissile material is U^{235} or Pu^{239}").

[32]The average lifetime of a given radionuclide may be computed from the half-life using the relation:

$$Ta = \frac{T_{1/2}}{0.693}$$

Where Ta is the average or mean life of a nuclide, $T_{1/2}$ is the half-life of the nuclide.

H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 426-427 (45th ed. 1972). Radon-222, for example, has a half-life of 3.82 days. The mean (average) life of ^{222}Rn atoms is 3.82/0.693, or 5.51 days.

[33]The comparison to radium is not purely coincidental. The unit of activity known as the Curie (Ci) was originally based upon the activity of one gram of radium, approximately 3.7×10^{10} distintegrations per second. S. Glasstone, Sourcebook on Atomic Energy 521 & n. (2d ed. 1958). Direct comparison with radium itself is tricky business. While ^{24}Na decays directly to stable ^{24}Mg upon emission of a β particle, ^{226}Ra decays largely according to the following scheme:

$$^{226}_{88}Ra \xrightarrow[T_{1/2} = 1.602 \text{ yrs}]{\alpha} {}^{222}_{86}Rn \xrightarrow[T_{1/2} = 3.82 \text{ days}]{\alpha} {}^{218}_{84} \xrightarrow[T_{1/2} = 3.05 \text{ minutes}]{\alpha}$$

$$^{214}_{82}Pb \xrightarrow[T_{1/2} = 26.8 \text{ minutes}]{\beta} {}^{214}_{83}Bi \xrightarrow[T_{1/2} = 19.7 \text{ minutes}]{\beta} {}^{214}_{84}Po \xrightarrow[T_{1/2} = 164 \text{ microseconds}]{\alpha}$$

$$^{210}_{82}Pb \xrightarrow[T_{1/2} = 21 \text{ years}]{\beta} {}^{210}_{83}Bi \xrightarrow[T_{1/2} = 5.01 \text{ days}]{\beta}$$

$$^{210}_{84}Po \xrightarrow[T_{1/2} = 138.4 \text{ days}]{\beta} {}^{206}_{82}Pb.$$ (This lead nuclide is stable.)

J. Gofman, Radiation and Human Health 444 (1981), PX-1046. [In this opinion, plaintiffs' exhibits are identified by a "PX-__; the defendent's by a "DX-__," followed by a specific exhibit number.] Radium ultimately decays to lead through emission of five α and four β particles. The decay chains for radionuclides in fallout are usually far shorter, yielding less continuous activity over longer periods of time.

[34]For example, consumer products such as luminous watchdials or home smoke detectors may contain 100 μCi or so of promethium-147 or americium-241, or 20 μCi of plutonium-238. See UNSCEAR Report (1977), at 95, PX-706/DX-605.

[35]The law of the conservation of energy, which is often called the First Law of Thermodynamics, may be stated in this way: energy can neither be created nor destroyed and therefore the total amount of energy in the universe remains constant. See e.g., Handbook of Chemistry and Physics F-76 (64th ed. Weast 1983); see also R. Feynman, The Character of Physical Law 68-77 (pap. ed. 1965). According to this principle, the energy released in nuclear reactions must go somewhere. It does not quietly dissipate into nothingness. It may change form—even become matter under certain circumstances—yet it is not lost.

[36]One of the early discoveries (ca. 1903) about the element radium, and α emitter, was that helium gas is continuously liberated from samples of radium salts. A sophisticated experiment by E. Rutherford and others in 1909 demonstrated that α particles were the source of the helium. S. Glasstone Sourcebook on Atomic Energy 55-56 (2d ed. 1958).

For course, some α particles will collide with the nuclei of other atoms, yielding nuclei of different elements and free neutrons or protons. Id. at 282-283; H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 479-484 (5th ed. 1972). Such collisions are so rare in comparison to ionization interactions that for practical purposes, the ionizing effect is the only one considered in evaluating the biological effects of radiation.

[37]For example, the stopping power of a particular material may be computed for α particles using this formula:

$$\frac{dE}{dx}(\text{MeV/m})^{8} = 4\pi r_0^2 z^2 \frac{mc^2}{\beta^2} NZ\left[\ln\left(\frac{2mc^2}{I}\beta^2\right) - \ln(1-\beta^2) - \beta^2\right]$$

where $r_0 = e^2/mc^2 = 2.818 \times 10^{-15}$ m = classical electron radius

mc^2 = rest mass energy of the electron = 0.511 MeV

$\gamma = T + Mc^2/Mc^2 = 1/\sqrt{1-\beta^2}$

T = kinetic energy = $(\gamma - 1)Mc^2$

M = rest mass of the particle

$\beta = v/c \quad c = 3 - 10^8$ m/s

N = number of atoms/m^3 for the material through which the particle moves
Z = atomic number of the material
z = charge of the incident particle ($z = 1$ for e^-, e^+, p, d; $z = 2$ for α)
I = mean excitation potential of the material

An approximate equation for I, which gives good results for $Z > 12$,[1] is

$$I(\text{eV}) = (9.76 + 58.8Z^{-1.19})Z$$

N. Tsoulfanidis, Measurement and Detection of Radiation 118-119 (1983) (ch. 4 of this book examines energy transfer and penetration of matter by radiation in considerable detail). A similar formula is available for use in dealing with high energy electrons, or β-particles:

$$\frac{dE}{dx}(\text{MeV/m}) = 4\pi r_0^2 \frac{mc^2}{\beta^2} NZ\left\{\ln\left(\frac{\beta\gamma\sqrt{\gamma-1}mc^2}{I}\right) + \frac{1}{2\gamma^2}\left[\frac{(\gamma-1)^2}{8} + 1 - (2\gamma^2 + 2\gamma - 1)\ln 2\right]\right\}$$

Id. at 1190.

[38]See e.g., N. Tsoulfanidis, Measurement and Detection of Radiation ch. 4 (1983).

[39]While the risks posed by α-emitters is popularly minimized by pointing out the stopping power of simple materials such as paper, or aluminum foil, α particles in the MeV range may penetrate from 30-60 μm in cell tissue. This distance encompasses the diameters of 2-6 cells. An α particle may carve a path through sensitive internal tissues that is strewn with hundreds of thousands of ionizations per μm.

[40]Some β-emitters are overbalanced in favor of protons and therefore seek greater stability through emission of β+ particles, or positrons. A positron is an electron that carries one unit of positive charge (rather than the usual negative charge). A positron (sometimes termed an anti-electron) is a particle of antimatter; if a β+ collides with a negative electron, both particles are annihilated with the release of γ rays.

[41]See e.g., 1 F. Whicker & V. Schultz, Radioecology: Nuclear Energy and the Environment 48-51 (1982). The kinetic energy (T) of the ionized electron is in fact

$$T = E_{\gamma} - BE$$

Where E_{γ} is the energy of the γ photon; BE is the binding energy of the elctron.

N. Tsoulfanidis, Measurement and Detection of Radiation 141 (1983). Where the energy of the γ ray is in the 100 kev to MeV range, while the binding energy is on the order of a few eV, this adjustment is a minor one.

[42]Unlike α or β- particles, which can be totally attenuated (i.e., reduced) by small thicknesses of many common materials, total attenuation of γ radiation is a more difficult task. While the intensity of a beam of γ photons decreases exponentially with the thickness of the bombarded material according to the relationship

$$I = I_{\alpha} - \mu\chi$$

where I_o is the initial intensity of a γ-ray beam I is the intensity after passing through thickness of x cm. of absorbing material having an absorption coefficent of μ ; e is the base of natural logarithms (i.e., $\approx$2.71828) some fraction of the γ rays will pass all the way through materials of significant thickness without interaction. See N. Tsoulfanidis, Measurement and Detection of Radiation 149-152 (1982) for treatment of attenuation calculations.

[43]Rather than attempt a catalogue of all types of gamma ray and neutron interactions with matter, this court has chosen merely to summarize the major type of reactions which are significant to human health and safety, or to the measurement of radiation exposure.

[44]The Einstein equation may also be expressed in terms of joules of energy, kilograms of mass and c = 3×10^8 meters per second. See e.g., W. Michels, et al., Foundations of Physics 233 (1968).

[45]Far more mundane energy-producing processes also annihilate matter, though in much smaller amounts. Eating a 200-Calorie candy bar (metabolism of which yields 200 calories of energy [1 Calorie = 1000 calories as used in physics]), for example, converts a small amount of matter into energy:

$$m = \frac{(2.0 \times 10^5 \text{ calories}) \times (4.184 \times 10^7 \text{ emp/calories})}{(9 \times 10^{20} \text{ cm}^2/\text{sec}^2)}$$
$$= 9.2977 \times 10^{-9} \text{ grams, or } 0.000000009297 \text{ grams.}$$

[46]In 1907, Albert Einstein ventured an interesting speculation based upon the relationship $E = mc^2$:

> It is possible that radioactive processes may become known in which a considerably larger percentage of the mass of the initial atom is converted into radiations of various kinds than is the case for radium [decay]

A. Einstein, 4 Jahub. Rad. Elektr. 411, 443 (1907) quoted in A. Pais, 'Subtle is the Lord. . . ' The Science and the Life of Albert Einstein 149 (1982).

[47]See e.g., O. Hahn, L. Meitner & F. Strassman, 106 Zeits. F. Phys. 249 (1937). But see O. Frisch, Atomic Physics Today 20-21 (1961).

[48]See O. Hahn & F. Strassman, 27 Naturwiss. 11, 89 (1939). The evidence was first analyzed in terms of splitting uranium into nearly equal fragments by Lise Meitner and Otto Frisch, who accurately calculated the energy released to be in the range of 200 MeV—and who first described the process as nuclear "fission"—in a paper dated January 16, 1939, which was sent to the British publication Nature. The paper was published in Nature in the February 11, 1939 issue. R. Moore, Neils Bohr 224-228 (1966); S. Glasstone, Sourcebook on Atomic Energy 385-389 (2d ed. 1958). See L. Meitner & O. Frisch, 143 Nature 239, 471 (1939).

[49]Fission of ^{235}U will release two or three neutrons immediately ("prompt" neutrons); some fission products will release addi-

tional neutrons—about 1% of the number of prompt neutrons (165/10,000 fissions)—over a period of a few seconds following fission. While the emission of delayed neutrons is too slow to affect the rate of reaction in an uncontrolled chain-reaction "bomb," delayed neutrons are important to calculations involving sustained reactions in nuclear reactors.

Fission of ^{239}Pu results in fewer delayed neutrons (61-63/10,000 fissions) being produced. 3 E. Hyde, et al., The Nuclear Properties of the Heavy Elements: Fission Phenomena 269 (1971 ed.); see generally id., 261-277; G. Keepin, T. Wimett & R. Zigler, 107 Phys. Rev. 1044 (1957).

[50]In a 2:1 chain reaction, assuming ideal conditions and no loss of neutrons to non-fission activity, such "generation" would be twice as large as the last. The number of fission events is easily calculated:

$$N_f = 2^x$$

Where N_f is the number of nuclei experiencing fission and x is the number of generations, assuming a reaction started by a simple neutron at $x = 0$.

This calculation is offered as a highly simplified model of the chain reaction process for illustration purposes only. See note 52 infra for actual ^{235}U chain reaction formulas.

[51]See W. Laurence, The Hell Bomb 13 (1950) citing an estimate in 1946 by Dr. M. L. E. Oliphant, a noted British physicist. Actual critical masses and theoretical formulations for uncontrolled fission remain secret.

[52]According to data in The Effects of Nuclear Weapons, fission of 1.45×10^{23} nuclei yields the equivalent of 1 kt of TNT. Id., at 13. Since one neutron is required per fission, 1.45×10^{23} neutrons must be made available to the fission process. Some neutrons inevitably escape the reaction altogether, while others are absorbed in non-fission nuclear reactions. The number of neutrons produced by one generation of fission (f) is reduced to that extent (l). For a given number of neutrons (N) present at a

given time the increase in the number of neutrons by the next generation of fission is

$$\chi = N(f - l) - N$$

the N number of neutrons having been absorbed to cause the fission in that generation.
If g is the generation time then the rate of neutron increase is

$$N = N_{\infty}{}^{x/g}$$

when N_o is the initial number of neutrons present, N is the number at a time (t) later, e is the base of natural logarithms ($\sim$2.7182818), and *x* is the quantity (f-*l*-1).

To simplify, let t/g (the number of generations that have elapsed during time t) be represented by *n* :

$$N = N_{\infty}{}^{x\eta}$$

S. Glasstone & P. Dolan The Effects of Nuclear Weapons 17 (3d ed. 1977). Using Glasstone's figures for ^{235}U, id., f = 2.5, *l* = approx. .5, and assuming N_o = 1 neutron initially,

$$\begin{aligned} 1.45 \times 10^{23} &= (1)e^{(\sim 1)\eta} \\ &= e^{\eta} \\ &= 53.3 \text{ generations} \end{aligned}$$

For ^{239}Pu, f averages 2.9 or so. J. C. Giddings, Chemistry, Man and Environmental Change 424 (1973).

[53]These calculations assume initiation of fission by a single neutron. A burst of 10,000 neutrons from a neutron source "trigger" would shorten the reaction time:

$$\begin{aligned} 1.45 = 10^{22} &= (10{,}000)_e(1)\eta \\ 1.45 \times 10^{18} &= e^{\eta} \\ \eta &= 41.8 \end{aligned}$$

Forty-two generations of fission initiated by a 10^4 neutron burst would yield 0.1 kt TNT equiv. 100-kt equivalence would take 59 generation's if Glasstone's formula is correct.

[54]See Glasstone & Dolan, supra at ¶ 1.58.

[55]Inertia is the term applied to the "tendency of undisturbed bodies to stay at rest" or to keep moving in a given direction. W.

Michels, et al., Foundations of Physics 83 (1968). The greater mass, the greater the inertia. Because of inertia, a densely packed mass of heavy atoms will resist a force that would tend to move it—even the force of a nuclear explosion, even 0.25 microseconds of resistance would permit many more fission reductions, producing a much higher yield.

[56]See e.g., N. Smith, Jr., Report of the Gabriel Project Study 9 (draft May 21, 1949), PX-679; Glasstone & Dolan, supra ¶ 1.50.

[57]In J. McPhee, The Curve of Binding Energy (1974), the author reports that the test of one device at NTS was designed to evaluate the lightweight metal beryllium as a neutron reflector. id., at 91-96.

[58]A megaton of explosive yield represents 1000 kiloton (kt), or the equivalent of one million tons of TNT, or 10^{15} calories, or 4.2×10^{22} ergs. S. Glasstone and P. Dolan, The Effects of Nuclear Weapons 636 (3d ed. 1977).

[59]The fusion reactions listed above are also extracted from Glasstone and Dolan, supra; S. Hecht, Explaining the Atom. 188-192 (rev. ed. 1954); H. Semat and J. Albright, Introduction t Atomic and Nuclear Physics 538-541 (5th ed. 1972); G. Amaldi, The Nature of Matter 266 (pap. ed. 1966).

[60]This particular lithium-6 reaction makes possible the development of a stable, solid fuel for fusion reactions, lithium hydride (LiH). If deuterium is the isotope used in the hydride, then it is readily available to react with the trituim produced by the reaction set forth above. See Glasstone and Dolan, supra at ¶ 1.70.

[61]Yield may also be boosted by using the high-energy neutrons produced in fusion reactions to curve fission of ^{238}U, perhaps wrapped in a blanket around the fission/fusion device.

According to Glasstone and Dolan, the total explosive yield of many thermonuclear devices is the sum of comparable fission and fusion yields. Id., at 22; see G. Amaldi, The Nature of Matter 279 (1966).

The largest thermonuclear device detonated so far is one of 58+ megaton yield, which was tested by the Soviet Union in 1962, somewhere in Siberia. J. Giddings, Chemistry, Man and Environment and Change, 451 (1973).

[62]As of 1979, the United States had conducted 106 nuclear tests in the Pacific, including the largest fission bomb ever detonated, a 500+ kt ("megaton range") device known as King, on November 15, 1952. See U.S. Dep't of Energy, Announced United States Nuclear Tests; NVO-209 (Jan. 1980), PX-728.

Two weeks earlier, on October 31, 1952, the United States put its then-existing state-of-the-art thermonuclear technology into the first such device ever exploded, the "Mike" shot. Mike produced a yield of 10.4 megatons, an explosion stunning in magnitude even for those who were directly involved in creating it. See e.g., J. McPhee, The Curve of Binding Energy 106-107 (1976). Herken, "Mad About the Bomb," Harper's 49, 52 (Dec. 1983).

[63]G. Herken, The Winning Weapon: The Atomic Bomb in the Cold War 1945-1950 (1981); J. Kunetka, Oppenheimer: The Years of Risk (1982); W. Laurence, The Hell Bomb (1951); R. Clark, The Greatest Power on Earth 256-271 (1980); D. Dietz, Atomic Science, Bombs and Power 194-225 (1954); J. Stokley, The New World of the Atom 245-253 (1957).

[64]The Government has offered as exhibits a number of memoranda, letters and reports written between 1948 and 1950 which detail the actual decision to proceed with atomic testing in Nevada. Serious discussion of a continental test site began as early as 1948 for reasons of economy and convenience. E.g., "Location of Proving Ground for Atomic Weapons, (Sept. 15, 1948), DX-77, id., (Sept. 27, 1948) DX-5; id., (Dec. 20, 1950), DX-843; AEC "Pre-Greenhouse Test Program," January 5, 1951, DX-83; AEC "Test Program" Dec. 29, 1950, DX-82. A memorandum circulated with the Navy observed that the "primary rational objection to a test of an atomic weapon within the continental limits is the radiological hazard." Rear Adm. W. Parsons to Cmndr, Joint Task Force Seven, (May 12, 1948), DX-77 at 18. See also, Report on "Project Nutmeg," DX-18; Holmes & Narver Report on "Emergency Proving Ground in Nevada,"

(August 1950), DX-10; memoranda, DX-3, 7, 8, 12, 15, 16, 20-24, 26, 28, 854.

[65]As much as 70-80% of the energy of a fission device may be released in this way as thermal radiation. Such temperatures—in the millions of degrees Celsius—instantly vaporize all matter within the radius of the fireball. See S. Glasstone & P. Dolan, The Effects of Nuclear Weapons ¶ 1.78, 2.03-2.04 (3d ed. 1977).

[66]The rapid expansion of the "fireball" generates a tremendous shock wave which can crush buildings and structures and hurl objects about with considerable force. See Glasstone & Dolan, supra, at chs. III-VI. Shock wave effects are not at issue in this lawsuit. Nor are other effects such as the electromagnetic pulse generated by a nuclear explosion. Id., at chs. X-XI.

[67]Some few fission products, e.g., krypton-86, zirconium-96, neodymium-150 and samarium-152, remain stable despite relatively high n/p ratios and do not contribute to fallout radioactivity. See Appendix A, infra. Each has an even number of protons and neutrons, a common trait among many stable nuclides. See. H. Semat & R. Albright, Introduction to Atomic and Nuclear Physics 546 (5th ed. 1972).

[68]That intensely radioactive fallout would be produced by explosion of a fission device was no surprise to the scientists who originally conceived of the idea. In 1940, Otto Frisch and Rudolph Peierls sat down and calculated the first practical mathematical model of an atomic bomb on the back of an envelope. The calculations evolved into a two-part memorandum to Sir Henry Tizard of the British Air Ministry, the second part of which warned, "Owing to the spreading of radioactive substances with the wind, the bomb could probably not be used without killing large numbers of civilians." O. Frisch & R. Peierls, "Memorandum on the Properties of a Radioactive 'Super-bomb'," File AB1/210, Public Record Office, Kew, London, quoted in R. Clark, The Greatest Power on Earth 90 (1980).

[69]The figure used by Glasstone, et al. (1950), based upon an aver-

age maximum β energy of 1.3 MeV and the observed quality that the average β energy is approximately Emax/3. See also, N. Tsoulfanidis, Measurement and Detection of Radiation (1983). Beta particles are thus emitted with a range of energies which is usually characterized by the maximum level. See also H. Semat & R. Albright, supra, at 442-445.

[70]Many if not all of the same heavy radionuclides are produced in the core of a functional nuclear reactor. See e.g., J. Gofman, Radiation and Human Health 469-475 (1981), PX-1046.

[71]The isotopes ^{240}Pu and ^{238}Pu have significantly shorter half-lives than does ^{239}Pu, and therefore have a greater radioactivity. They are produced by nuclear processes in differing proportions:

isotope	half-life (yrs.)	% yeild by weight*
^{238}Pu	86	1.5
^{239}Pu	24,400	60
^{240}Pu	6,580	22
^{241}Pu	13.2	12
^{242}Pu	379,000	4.5

*The % yield values are those for plutonium residue in spent "high burn-up" nuclear reactor fuels. UNSCEAR Report (1977) at 204, PX-706/DX-605. The actual values for specific nuclear weapons detonations may vary somewhat.

[72]The specific activity (SA in curies/gram) of plutonium-239 may be computed using the formula:

$$SA = \frac{\ln 2(N_A)}{T_{1/2}(A)(NCi)(3.16 \times 10^7 \text{ sec./year})}$$

Where the natural logarithm of 2 (ln2) = 0.693, N_A is Avogadro's Number, $T_{1/2}$ is the half-life of the nuclide in years; A is its mass number (in grams); and N_{ci} is the number of nuclear disintegrations per second in 1 curie of radioactive material. See N. Tsoulfanidis, Measurement and Detection of Radiation 101 (1983). Substituting numerical values, the specific activity of ^{239}Pu ($^{SA}Pu^{239}$) equals:

$$\frac{(0.693)(6.022 \times 10^{23})}{(239 \text{ gm})(2.44 \times 10^4 \text{ yr.})(3.16 \times 10^7 \text{ sec./yr})(3.71 \times 10^{10} \text{ d/sec})}$$

$$= 6.1 \times 10^{-2} \text{ Ci/gm. or } 0.61 \text{ Ci/gm}$$

Using specific activity as a conversion factor, 320 kCi of ^{239}Pu would have a mass of

$$(3.2 \times 10^5 Ci/6.1 \times 10^{-2} Ci/gm) = \chi \text{ gm } ^{239}Pu$$
$$\chi = 5.24 \times 10^6 \text{ gm } ^{238}Pu$$

or nearly 5¼ metric tons of plutonium-239. Adjusting this figure to account for 10% from other sources, more than 4.7 metric tons is traceable to nuclear testing.

[73]The UNSCEAR Report (1977), PX-706/DX-605 gives an estimated figure of 3 tons for plutonium deposited on the earth, perhaps reflecting some adjustment for isotopes of the element having shorter half-lives than ^{239}Pu. See id. at 148. Yet it is not explained, and 86-year ^{238}Pu is separately quantified at 26 kci.

[74]Not all "unburned" uranium is converted by neutrons into plutonium. Because of its much longer half-lives, uranium adds far less to the total radioactivity than does plutonium.

nuclide	half-life (yrs)	SA (Ci/gm)
^{233}U	1.62×10^5	9.45×10^{-3}
^{235}U	7.1×10^8	2.1×10^{-6}
^{238}U	4.51×10^9	3.3×10^{-7}
^{239}Pu	24,400	0.0061
^{240}Pu	6,580	0.226
^{238}Pu	86	17.44
^{241}Pu	13.2	112.2

Uranium is nevertheless a component of fallout from any bomb containing it, and cannot be wholly disregarded.

[75]This is particularly important to keep in mind when evaluating recent studies which attempt to compute total fallout activity based upon the quantity of a few fission products still present in the environment. While the quantities and proportions of other shorter-lived fission products follow the "two-hump" curve, induced activity does not. Retroactive fallout calculations based wholly on fission products are necessarily in error to some degree.

[76]Where L_e is the effective decay constant (the sum of $L_R + L_B$),

$$Te = \frac{\ln 2}{L_e}$$

N. Tsoulfanidis, supra, at 497.

[77]See e.g., S. Glasstone and P. Dolan, supra ¶¶ 9.59-9.100, at 414-435; G. Felt, "Methods of Predicting Radioactive Fallout," Los Alamos Scientific Laboratory (1956), DX-719; G. Felt, "Fallout Model" memorandum. July 7, 1952, PX-23/DX-990; 722 Maj. N. Lulejian, "Forecast Fall-Out Plot," PX-22/DX-720; Lt. Col. C. Spohn, "Fallout Prediction" memorandum, July 2, 1952, DX-714; G. Felt, "Forecasting of the 10r isodose Line," June 1954, DX-716; C. Buell, "Notes on Rainout from Atomic Detonations," Aug. 2, 1954, DX-718; Wright, et al., "A High-Speed Computer for Predicting Radioactive Fallout," 58 J. Research of Nat'l Bureau of Standards 101 (Feb. 1957), DX-721; D. Allen, "Seasonal Weather Considerations in Planning NPG Operations," (ca. 1953), DX-30/PX-98.

[78]The presence of "hot spots" was no longer a surprise after their original discovery in the fallout pattern from the TRINITY test at Alamagordo, New Mexico in 1945. See F. Reines, "Discussion of Radiological Hazards Associated with A Continental Test Site for Atomic Bombs," LASL, (Sept. 1950), in DX-13, 18 App. E/PX-89 at 18, 21, 23; "1948 Radiological and Biological Survey of Areas in New Mexico Affected by the First Atomic Bomb Detonation," UCLA, pt. 1, PX-352 at 43 ("The fallout [at Chupadera Mesa] is somewhat spotty and readings of activity vary from less than 0.1 milli-roentgen per hour to as much as 6.5 milli-roentgens per hour in a few places."); S. Glasstone, et al., The Effects of Atomic Weapons ¶¶ 8.57-8.83 at 268-276 (1950), PX-690/DX-470.

[79]On paper, a dose of radiation expressed in Grays looks smaller than the same dose expressed in rads or millirads. Units must, however, be kept in perspective. A lethal acute dose of radiation would be a "mere" 6 Gy.

[80]The equation gives a fair estimate where the total period (T) considered is much greater than the effective half-life (Te). For nuclides with long effective half-lives, a different formula is used. See Tsoulfanidis, supra, at 498.

[81]The example figure is based on a 20-kt explosive yield. Larger devices produce proportionately larger total yields of radioactive fission product.

[82]The use of "Q" in this context should not be confused with "Q" as used in nuclear physics to represent nuclear reaction energies. See e.g., H. Semat & J. Albright, Introduction to Atomic and Nuclear Physics 470-471 (5th ed. 1972).

[83]Recent years have seen increasing use of the equivalent international unit, the Sievert (Sv). A dose of 1 Sievert equates with 100 rems. See N. Tsoulfanidis, Measurement and Detection of Radiation, supra, at 487.

[84]One Joule (J) is the energy equivalent of 1.000165×10^7 ergs. Handbook of Chemistry and Physics, at F-314 (64th ed. Weast 1983).

[85]The literature concerning potential genetic effects is voluminous and ever-expanding. See e.g., UNSCEAR Report (1977) PX-706/DX-605, pt. 2; Committee on the Biological Effects of Ionizing Radiation, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980 71-129 (1980), DX-1025. J. Gofman, Radiation and Human Health 760-853 (1981), PX-1046.

[86]The UNSCEAR Report (1977), PX-705/DX-605, treats at some length the question of the quantity, characteristics and effects of worldwide fallout from all sources, See id., at 115-164 and references cited. Beyond a few documents offered into evidence, the parties to this action have not focused this action upon the question of relative impact of worldwide fallout on Utah communities.

[87]See e.g., Report of Advisory Comm., Div. of Biol. & Med., AEC Mar. 26, 1954, DX-33, 35.

[88]As one court has observed, "it would be difficult to conceive of any official act, no matter how ministerial, that did not admit of some discretion in the manner of its performance." Ham v. City of Los Angeles, 46 Cal. App. 148, 162, 189 P.2d 462, 468 (1920).

[89]At trial, counsel for the Government reasserted the view that the plaintiffs' action is barred by 28 U.S.C. § 2680(h) (1976), the "misrepresentation" exception to the Federal Tort Claims Act. While it is clear from the opinions in United States v. Neustadt, 366 U.S. 696 (1961) and Reynolds v. United States, 643 F.2d 707 (10th Cir. 1981) that the exception extends to claims for negligent misrepresentation, it remains equally clear that the interests and conduct encompassed within "misrepresentation" and "deceit" as used in § 2680(h) are those arising in the context of a business, commercial, investment, or economic context. Neustadt, supra, 366 U.S. at 706-711 & nn. 16-26. While Reynolds asserts a claim for a physical rather than appropriational harm, the connection tying the conduct of the Government to the injury is one common in § 2680(h) cases: approval of a residence for purposes of mortgage approval. Though Reynolds remarks that the exception "has been broadly construed to include false representations of any type," id., 643 F.2d at 712, the cases cited relate either to mortgage approvals or to inspections affecting the market value of goods or property, or some adverse impact on a purchase arrangement.

Reynolds must, of course, be read in light of the court's final comments in Neustadt that

> Our conclusion neither conflicts with nor impairs the authority of Indian Towing Co. v. United States, 350 U.S. 61, which held cognizable a Torts Act claim for property damages suffered when a vessel ran aground as a result of the Coast Guard's allegedly negligent failure to maintain the beacon lamp in a lighthouse. Such a claim does not "arise out of. . . misrepresentation," any more than does one based upon a motor vehicle operator's negligence in giving a misleading turn signal. As Dean Prosser has observed, many familiar forms of negligent conduct may be said to involve an element of "misrepresentation," in the generic sense of that word, but "[s]o far as misrepresentation has been treated as giving rise in and of itself to a distinct cause of action in tort, it has been identified with the common law action of deceit," and has been confined "very largely to the invasion of interests of a financial or commercial character, in the course of business dealings."

Prosser, Torts § 85, "Remedies for Misrepresentation," at 702-703 (1941 ed.). See also 2 Harper and James, Torts, § 29.13, at 1655 (1956).

Id., 366 U.S. at 711 n. 26. The duty owed to the plaintiffs in this case and the negligent conduct alleged as the basis of their claim in no way relates to any purchase, mortgage, sale, commercial or business investment, or other economic relationship. While some Test Organization personnel were at times concerned with "selling" the idea of continental testing, the sense was distinctly different, as was the context. The test site personnel, like our forlorn yet hypothetical Los Alamos truck driver and his turn signals, owed a duty of care to avoid injury to the plaintiffs apart from any commercial transaction or relationship. As with the truck driver, the question is really one of public safety.

As this court has previously held, in light of Neustadt and its progeny, § 2680(h) is simply irrelevant to this case. See W. Prosser, Handbook of the Law of Torts §§ 105-110 (4th ed. 1971).

[90]The parties have offered into evidence a great number of press releases, statements, remarks prepared by AEC officials and other documents related to public information. See e.g., Letter from Dr. W. F. Libby, AEC, to Dr. Albert Schweitzer, (press release) Apr. 25, 1957, PX-239/DX-551. The documents are consistent in tone and content. See generally, DX-60, 60A-60KK, 61A-61JJ, 62-66, 1200-1236, 440-443, 46, 444, 435-438, 681, 556, 588-562, 545, 534-539, 595, 633, 629, 570, 629, 680, 682, 683, 573, 598, 747, 541-542, 546, 552, 557, 561, 547, 549, 555-56, 620-621, PX-225-227, 229, 194, 260, 252, etc. See also "Background Information on Nevada Nuclear Tests," PX-245/DX-622 (May 1, 1957); PX-34, PX-210, DX-625, etc.

[91]The plaintiffs in this action were not regular readers of Science, Health Physics, or the Bulletin of Atomic Scientists.

[92]Perhaps the Government should be stopped from now asserting that plaintiffs be imputed to have knowledge of a causal relation-

ship that it has always reassured people did not exist. Why should plaintiffs be charged with the views of a Pauling or a Sternglass when so much more was said by the Government—in films, pamphlets, press statements—to the contrary?

[93]28 U.S.C. § 2680 (1982 ed.) details several specific exceptions to liability under the Federal Tort Claims Act, such as the discretionary function exception discussed supra. In addition, the Supreme Court has held that the Act's grant of jurisdiction over claims arising from "negligent" or "wrongful act or omission," 28 U.S.C. § 2672 (1982 ed.) does not include any strict liability claims. See Laird v. Nelms, 406 U.S. 797 (1972).

[94]As in the 1946 Act, the AEC is authorized and directed to make arrangements for research and development activities relating to ". . . (5) the protection of health and the promotion of safety during research and production activities." Id., 42 U.S.C. § 2051(a)(5) (1976 ed.).

[95]Act of June 11, 1946, c. 324, 60 Stat. 237, as amended by Pub.L. 89-554, Sept. 6, 1960, 80 Stat. 383, and other legislation, codified at 5 U.S.C. §§ 551-59, 701-06, etc.

[96]National Environmental Policy Act of 1969, Pub.L. 91-190, Jan. 1, 1970, 83 Stat. 852 codified at 42 U.S.C. §§ 4321, 4331 et. seq., as amended.

[97]For example, the Faroe Islands in the North Atlantic near Iceland experienced unusually high levels of strontium-90 in milk (150+ pci ^{90}Sr/gm Ca in 1964 compared to 10+ pci ^{90}Sr/gm. Ca in San Francisco). UNSCEAR Report at 130-131 (1977), at 130-131 PX-706/DX-605.

[98]Absent the constraints of the Federal Tort Claims Act, open-air detonation of nuclear weapons might well join the category of imminently dangerous activities justifying imposition of strict tort liability. See generally W. Prosser, Handbook on the Law of Torts (4th ed. 1971). One could very sensibly hold that one who detonates nuclear weapons does so at his own risk, almost assuming the liability of an insurer for losses or injury resulting therefrom.

[99]The parties have submitted a number of periodic reports from the health physics division of the Oak Ridge National Laboratory, which prove useful to contemporaneous indicators of health physics concerns and practices, particularly those relating to monitoring of contamination in persons and environment. See PX-692-696, 713-716; DX-471-511.

[100]See Green, "The Duty Problems in Negligence Cases," pt. I, 28 Colum. L. Rev. 1014 (1928); id., pt. 2, 29 Colum. L. Rev. 225 (1929); Green, "Duties, Risks, Causation Doctrines," 41 Text. L. Rev. 42, 45, 58 (1962); Thode, supra, 1977 Utah L. Rev. at 8-10. To say that defendant's conduct is the legal cause, or the proximate cause of plaintiff's injury expresses a determination that the scope of the duty—and of the laws protection—extends to the particular risk to the plaintiff. That is the subject of the lawsuit. W. Prosser, Handbook of the Law of Torts § 42 (4th ed. 1971).

[101]In evaluating that state of knowledge, one confronts "the most difficult task in studying past science: to forget temporarily what came afterward." A. Pais, 'Subtle is the Lord': The Science and the Life of Albert Einstein 9 (1982).

[102]The book Radiation Protection Standards, DX-694, by the same author, gives more abbreviated treatment to the same subject matter as the cited reference.

[103]See Muller, "Artificial Transmission of the Gene," 66 Science 84 (1927); Sax, "The Cytological Effects of Low-Intensity Radiation," 111 Science 332-33 (Sept. 1950), PX-648.

[104]That is, "[i]f film badges or dose meters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurage account of the radiation dose received. . ." Id. Use of film badges or dosimeters on the offsite population was at least a scattered and intermittent activity.

[105]G. M. Dunning "Radiations from Fallout and Their Effects," at 21 (May 1957), DX-563, reprinted in Hearings, "The Nature of Radioactive Fallout and Its Effects on Man," Joint Committee on Atomic Energy, 85th Cong., 1st Sess., (1957), PX-831C at 177

recommends "early removal of the body contamination since higher doses are delivered during early times after fallout" in order to avoid biological injury from beta radiation.

[106]Terrill's further comments about the utility of washing are helpful:

> An emergency measure recommended in the Pacific is to stand in the lagoon immersed as far as possible in the water while continuing to wash off exposed portions of the body. This recommendation is based on the fact that the fallout settles from the surface and allows water to attenuate the radiation.

Id., PX-831C, at 334.

[107]Other symposium participants, such as Col. James T. Brennan ("Mathematical Aids in the Understanding of the Biological Hazards of Residual Radiation," id. at 127), concurred in Dr. Morgan's concerns about measurement:

> Col. Brennan: xxx In general, then, the responsive action would be to either protect against [beta radiation] in terms of clothing or time or geometry, and be very sure you have good protection or if you can't do that, you are pretty much committed to measure it. At least measure it often enough to control the hazard, however difficult that may be. That is at least the direction one ought to go.

Id., PX-641, at 146.

[108]In further discussion of the plutonium hazard, the handbook states:

> It is only under certain unexpected conditions that plutonium is likely to constitute an important hazard following an atomic bomb explosion. In most cases, the danger due to this element can be ignored, compared with that due to fission products, for a period of at least two months, in any event. By this time, it may be presumed that an inhabited locality will have been largely decontaminated.

Id., PX-690/DX-470, at 362-363 (emphasis added). What if local decontamination measures are not undertaken? Radiation hazard?

[109]The original 1953 draft of the Project Sunshine study underestimated the half-life of its subject, ^{90}Sr, by at least eight years (19.9 yrs. compared to 27.7 yrs [1956] or 28.1 yrs. [Handbook of Chemistry and Physics, 1983]). See Draft Report, 1953, PX-1027/DX-743.

[110]See PX-692, 693, 694, 695, 696, 713, 714, 715, 716; DX-471 through 511. (Note: prior to being known as the Oak Ridge National Laboratory, the establishment was known as Clinton Laboratories. See 2 R. Hewlett & F. Duncan, Atomic Shield: A History of the United States Atomic Energy Commission 120-123, 224, 420-421 (1972), DX-1002.)

[111]See AEC Memorandum, "Location of Proving Ground for Atomic Weapons," with appendices, AEC 141/7 (Dec. 13, 1950) DX-18; Memorandum, "Review of Establishment of Continental Test Site," (Sept. 1953) PX-52/DX-1A; Part V, supra; Tr. at 5974-6015 (testimony of Dr. Norris E. Bradbury); Tr. at 6450-6490 (testimony of Gen. Kenneth Nichols); Tr. at 6491-6562 (testimony of Gen. Kenneth E. Fields).

[112]A number of memoranda originally describing in some detail the specifics of each test program have been offered in exhibits. Though very heavily edited (with many pages totally blank), the technical significance of the design of many tests comes through. See e.g., DX-82, 83 (Ranger); DX-98, 99, 100, 101 (Buster-Jangle); DX-142, 143 (Tumbler-Snapper); DX-158, 172, PX-1038 (Upshot-Knothole); DX-202, 319-320 (Teapot); PX-119/PX-691/DX-393, DX-391, 394, 395 (Plumbbob).

[113]See e.g., "Air Weather Service Participation in Operation Buster-Jangle," (Dec. 1951), PX-115; C. Spohn, "Activities of the Special Weather Advisory Service," Operation Tumbler-Snapper WT-552 (Nov. 1952) DX-155.

[114]Other isotopes of plutonium (^{238}Pu, ^{240}Pu, ^{241}Pu) presented varying degrees of hazard depending upon quantity and the specific activity of each. See Part III, supra. Each is equally likely to be absorbed or retained in bone tissue, or to persist in the inner linings of the lungs.

[115]See e.g., J. Gofman, Radiation and Human Health 431-443 (1981) PX-1046; Martland, "The Occurrence of Malignancy in Radioactive Persons," 15 Am. J. Cancer 2345-2516 (Oct. 1931), PX-868 (original comprehensive study of radium watch-dial painters).

[116]See PX-686(a)/DX-79 (Ranger); DX-705, 351, 350, PX-117, PX-28/DX-689 (Teapot); DX-396, PX-27/PX-836/DX-690, PX-685 (Plumbbob); DX-432 (Hardtack II). The post-series reports on radiological safety often include the rad-safe plans and instructions for the series. E.g., T. Collison, "Radiological Safety Operation," Operation Upshot-Knothole, WT-817 (June 1953), PX-698/DX-194.

[117]See DX-85 (Ranger); PX-907, DX-119 (Buster-Jangle); PX-908/ DX-141, DX-144, DX-1178 (Tumbler-Snapper); DX-270, 271, 184, 185, 190, PX-909/DX-157-303 (Upshot-Knothole); PX-910/ DX-205, DX-323 (Teapot); DX-376, PX-911/DX-392, PX-224/ DX-387, DX-405, PX-217 (Plumbbob).

[118]See PX-704/DX-730, DX-699 (Ranger); DX-106-112, PX-85/ DX-114, 117, 132, 125, 122, 123, 131 (Buster-Jangle); PX-736/ PX-86/DX-115, DX-154, PX-737 (Tumbler-Snapper); DX-198, PX-13, 11, 209 (Upshot-Knothole); DX-352 (charts), DX-358 (Teapot); DX-429 (Plumbbob); DX-448, 367, 368, 452, 453 (Hardtack II).

[119]Tr. at 4357-4476 (testimony of Dr. Gordon M. Dunning); Tr. at 4477-4558 (testimony of Dr. Howard L. Andrews) Tr. at 4560-4702 (testimony of William S. Johnson); Tr. at 4705-4802 (testimony of Melvin Carter); Tr. at 5918-6015 (testimony of Dr. Norris E. Bradbury); Tr. at 6016-6057 (testimony of James E. Reeves); Tr. at 6450-6490 (testimony of Kenneth Nichols).

[120]See e.g., 2 Proceedings of the Off-Site Monitors Workshop, at 84 (June 26, 1980), PX-288 (statement by Morgan S. Seal) ("[W]e knew for a fact then that those oxidating techniques completely eliminated any iodine in the material that you were treating. So that the milk residue has no iodine at all in any of the gross betas that we determined on them.")

[121]See e.g., J. Harley, et al., "Summary of Analytical Results From the HASL Strontium Program, July Through December, 1956," in Hearings, "The Nature of Radioactive Fallout and Its Effects on Man," Joint Comm. on Atomic Energy, 85th Cong. 1st Sess., at 591, 603 (1957), PX-831C ("Tests have shown that dry ashing of milk results in loss of cesium 137, even at low temperatures. No cesium 137 results on milk will be reported until improved techniques are available").

[122]One finds an interesting comment in Y. Ng, et al. Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Device—IV. Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere, Lawrence Livermore Radiation Laboratory, (May 1968), PX-720, at vi = "It is obvious that had ^{131}I been measured in mild during the early period of testing, its dosimetry would not now be a problem."

The total absence of reliable internal exposure data, particularly during the heaviest fallout of UPSHOT/KNOTHOLE highlights the wisdom of another observation from the same source:

> Off-Site radiological safety programs should and can be conducted with the same degree of planning and precision as laboratory experiments.

Id., PX-720, at v.

[123]Even when the NCRP shifted away from routine blood count monitoring of radiation workers, it reiterated the view that "Blood counts are a necessary part of the medical examination of anyone overexposed to penetrating ionizing radiations." NCRP General Communication No. 30, June 21, 1955, quoted in L. Taylor, supra, DX-693, at p. 8-259. In 1953, the ICRP guidelines found blood counts "desirable" for workers who received doses exceeding two-thirds of the maximum permissible doses (0.3 r per week). Id., at p. 8-260.

[124]The "Windscale incident" refers to an event on October 10, 1957 at the Windscale Works of the U.K. Atomic Energy Authority in which a reactor core overheated, resulting in an explosive release of 20,000 curies of radioactive iodine-131 and

other nuclides into the neighboring environment. An immediate, comprehensive milk monitoring program was initiated in the 200 square miles around the plant. Milk distribution from a number of farms was temporarily halted. Resumption of normal milk distribution began on November 21, 1957, more than a month after the release—after careful monitoring disclosed that radioactive contamination had again dropped to very low levels. J. Feinberg, The Story of Atomic Theory and Atomic Energy 220-223 (pap. ed. 1960). Dr. Morgan testified that monitors in that case checked the milk using instruments at the farms themselves. Tr. at 2826-2827.

According to Feinberg,

> The sober, coolheaded handling of the incident will serve as a classic model for handling of similar accidents in the future. It undoubtedly prevented general panic in the area and prevented the mishap from turning into a disaster.

Id., supra, at 222-223. See NCRP Rep. No. 55, Protection of the Thyriod Gland in the Event of Release of Radioiodine 4, 14 (1977), DX-1179.

[125]Counsel for plaintiffs highlight a specific incident recounted by participants in the off-site monitors workshop in 1980. Morgan Seal described working with an associate on calculating the amount of radioactive iodine in milk samples based upon assumptions (1) that the beta activity remaining in the milk ash was ^{90}Sr, ^{89}Sr, and ^{137}Cs, and (2) that iodine would have been present in an amount proportional to its ratio in the original fission product yield.

> So anyway, Frank and I did a few of these. . . and we showed it to Gordon Dunning. He got mad, red in the face, took it, threw it on the floor and stomped on it, "Don't you do that." So I don't know whether it meant a damn thing or not, it is immaterial, but it sure got Gordon excited.

2 Proceedings, Off-Site Monitors Workshop (1980), PX-288, at 85. The precise significance of the episode remains unclear. See Letter from M. Seal to B. Church, Aug. 8, 1981, DX-1117; Tr. at 4410-4412 (testimony of Gordon Dunning).

[126]See e.g., K. Larson, et al., "Distribution, Characteristics and

Biotic Availability of Fallout, Operation Plumbbob," WT-1488 (1966), PX-341, Refs 14, 15 at p. 36.

[127]See e.g., T. Shipman, "Special Rad Safe Problems—Operation Bungle [Buster-Jangle]," July 11, 1951, PX-88, at 2:

> I feel that using the 3.0 r permissible exposure for the operation does not seriously violate the spirit of the AEC directive on this matter. Actually we are giving ourselves a little leeway to permit the concurrent beta exposure which is not measured. [Emphasis added].

[128]Participants in the Off-Site Monitors Workshop recalled reassigning badges from cowboys and ranch workers to others because of badge placement problems. 2 Proceedings of the Off-Site Monitors Workshop 74-75 (June 26, 1980), PX-298.

[129]Some film badges had been used to monitor places in earlier test series, but only a few individual residents.

[130]In H. Andrews, "Residual Radioactivity Associated with the Testing of Nuclear Devices within the Continental Limits of the United States," Nat'l Inst. of Health, (Sept. 13, 1953), PX-68 comments that:

> Accurate dose determinations on a general population, using film badges or other integrating devices is practically impossible because of the impossibility of controlling the use of the badge. High readings due to faulty badges or accidental or malicious misuse could put the test organization in an indefensible position.

Id., at 9. The PLUMBBOB badge study experienced no serious difficulty. See J. Reed, supra, PX-340/DX-766, at 5-26.

[131]Indeed, the stubborn persistence of fallout radioactivity in the off-site environment is the underlying premise of much of the Government's field work involving current measurement of fallout deposition, at least to date. See, e.g., H. Beck & P. Krey, "External Radiation Exposure of the Population of Utah From Nevada Weapons Tests," EML-401 (Jan. 1982), DX-1110.

[132]While several comments made at the Off-Site Monitors Work-

shop indicate that a number of original monitoring records had been routinely discarded or destroyed, the lost data is not materially different in kind from that which has survived either in official files and reports or the private files of participants. See 1 Proceedings of the Off-Site Monitors Workshop, at 66 (1980), PX-287.

[133]In the first series, RANGER, it was observed that "[i]f a man happened to be actually in the path of the low-flying dust cloud he could measure significant amounts of activity while airborne particles, very small in size, were actually around him. When the dust cloud had passed, there seemed to be little or nothing deposited on the ground and no residual activity of any significance." 5 Operation Ranger: Program Reports—Operational, WT-204 (July 1952), PX-741 at 59. The lesson was relearned in BUSTER/JANGLE: "of particular interest in both the Jangle shots was the large amount of extremely radioactive airborne dust which could pass a given point without leaving any significant deposition on the ground." T. Shipman, "Radiological Safety," Operation Buster-Jangle, WT-425[EX] (July 1953), PX-361, at 11.

[134]E.g., T. Shipman, "Radiological Safety," Operation Buster-Jangle WT-425 (EX), supra at 12:

> At the time of Operation Ranger the dangers and difficulties of having shots too close together were appreciated, and at that time it was agreed that future detonations would be spaced adequately far apart. At Operation Buster this lesson was forgotten or neglected; consequently shots were crowded together with inadequate time for personnel to function efficiently.

[135]See also W. Johnson, et al., "Report of the Advisory Personnel to the Air-Sampling Program," Operation Tumbler-Snapper, WT-566, (June 1953) PX-362, at 10, points out that none of the military personnel assigned to air-sampling "had ever received any previous training in any of the procedures associated with a fallout study. This problem would not have been so serious were it not for the fact that, except for the four people noted above, no other personnel were permanently assigned to the

program. Each test brought a new group of operators inexperienced in the proper techniques, and little use was made of the experience gained by members of the group on succeeding tests. Personnel were not assigned to the program until a few hours before it was necessary to dispatch them to their respective stations to perform duties in which they had been only briefly indoctrinated. . . ."

[136]See also W. Johnson "Report of the Advisory Personnel. . ." Operation Tumbler-Snapper, WT-566, PX-362, supra at 10:

"Particle size measurements were made using the Casella cascade impactor with Whatman 41 filter paper in the fifth state. Because of a shortage of pumps to supply the required flow through the impactors, only four to six measurements were possible on each test. The units which were available, however, were placed in areas in the anticipated path of the fallout, based on an early meteorological forecast, and, since this usually changed considerably with later predictions, not all impactors received enough activity to make a significant particle-size analysis. There is considerable question as to the validity or interpretation of particle-size measurements by this method, but it still remains the most practical procedure for routine field use. . ." [Emphasis added.]

That being so, it seems a little odd that use of cascade impactor equipment ended with UPSHOT/KNOTHOLE series in 1953. See 2 "Proceedings of Fourth Dose Assessment Advisory Group Meeting," Dec. 3, 1981, DX-1019 at 286. Monitory personnel had discovered that in going to 24-hour operation of the cascade impactors,

> More frequent changes in collecting surfaces were necessary to determine the exact arrival time of the material collected. This is important because the rapid decay during the first 24 hours necessitated a considerable extrapolution from the counting time back to the arrival time. On the last four shots, filter papers were changed hourly. Both these changes proved of value and should be considered in future tests.

Id., PX-362 at 10. In TEAPOT (1955), however, the high-volume air samplers were operated for 28 hours with 7 filter changes between 1 and 16 hours apart. J. Sanders, "Report of

Off-Site Radiological Safety Activities," PX-338, at 12. About 230 samples were analyzed following each test. Id.

[137]See e.g., O. Placak, et al., "Off-Site Radiological Safety Report," Operation Plumbbob, (1957), PX-339/DX-427; K. Larsn, "Distribution, Characteristics, and Biotic Availability of Fallout," Operation Plumbbob, WT-1488 (July 1966), PX-341.

[138]In BUSTER/JANGLE, for example, the Jangle Feasibility Committee set forth "radiological safety requirements" that specified that the "external dose of gamma radiation to nonparticipating inhabitants shall not exceed the accepted international permissible dose level of 300 mr/week, which may be integrated over a maximum of 10 weeks." T. Shipman, "Radiological Safety," Operation Buster/Jangle, WT-425 (EX) (July 1953), PX-361, 1023/DX-130 at 41.

[139]Even the 1954 Report's recommendations maintain this cycle:

> Advance warnings should be issued within the NPG region at the earliest possible moment, this procedure to be adopted only if pre-test educational efforts suggested herein are activated.

Id., PX-51/DX-1 at 44 (emphasis added).

[140]Recalling that beta exposure rates often exceeded gamma rates by 3:1, 10:1 or even 600:1, external beta exposure at the listed "hot spots" could easily have ranged above 100 rads.

[141]By then, however, many people had been directly exposed to the HARRY debris. As Off-Site Radiological Safety Officer William Johnson comments in retrospect, "I think we have to admit that we got the people in St. George indoors too late in this case [Harry]. Just like we stopped the cars too late." 1 Proceedings of the Off-Site Monitors Workshop, at 144 (1980), PX-287 (remarks of W. Johnson); Tr. at 4681, 4687-4689 (testimony of William S. Johnson); see also Memorandum, "Decontamination of Vehicles at Caliente, Nev., Shot IX, May 19, 1956," DX-197.

[141A]The pamphlet further comments that

> Over a period of many years, a human may safely receive in small doses a total amount of radiation which would cause fatal illness if administered to his whole body within a period of a few minutes

Id., DX-1153 at 35. If a lethal dose is 400 r or more, does that mean someone may safely receive 20 r per year for 20 years "without hazard"? After all, doesn't it say that it takes at least 25 r to produce "detectable bodily effects"? Contrary to established principles of radiation protection at that time, the booklet does nothing to discourage this kind of reasoning.

[142]Accord, J. Novak, ed., "Radiation Safety Guide," Argonne Nat'l Laboratory, (June 1956), DX-687.

[143]Even so, the booklets do not explain in any specific terms how those instructions or warnings would be communicated in an emergency fallout situation (radio? telephone? door-to-door?)—a situation not materially different from that during UPSHOT/KNOTHOLE, for example, following the HARRY test. Perhaps the assumption was that no "need" to communicate emergency instructions would ever arise.

[144]See Part VIII(A), supra.

[145]Accord, J. Novak, ed., "Radiation Safety Guide," Argonne Nat'l Laboratory, at 49, 50 (June 1956), DX-687:

> The best method for general decontamination of the exterior surfaces of the hands and other parts of the body is a thorough washing with soap and water, or with detergent, such as Tide or pHisoderm.. . .
>
> * * * *
>
> Wash thoroughly for two to three minutes by the clock. Use tepid (not hot) water and a mild soap or detergent such as Tide or pHisoderm. Cover the entire surface of the contaminated area with a good lather. Rinse off completely with water. Repeat the process at least three times. Do not use abrasive or highly alkaline soaps or powders.

[146]Versene, or ethylenedinitrilo tetraacetic acid (EDTA), is what is known as a chelating agent, i.e., a chemical which attaches itself to a metal ion, forming a complex which, in the case of EDTA, is water-soluble. The use of such chemicals as decontamination aids had been tested at the 1946 Bikini tests with some degree of success. J. Hirschfelder, et al., The Effects of Atomic Weapons §§ 10.50-10.54, at 328-329 (1950), PX-690/DX-470. Of course, that handbook points out that "the obvious use of soap and water cannot be neglected."

[147]Of course, longer-lived strontium-89, strontium-90, iodine-127 and cesium-137 would persist in the dairy products for many years.

[148]Even supposing that soon after a routine test at 5:00 A.M., the NTS command center calcuated a possibility of 25+ rad fallout for an off-site community, no immediate procedure seems to have been available for communicating a crisis-situation warning. There was no general instruction, such as "listen to radio station X on test mornings." The weaknesses evident in the HARRY episode in St. George seem neither to have been anticipated nor remedied.

[149]The Ybarra court went on to apply the doctrine of res ipsa loquitur to permit a presumption of negligence to be drawn from the fact of the injury itself. For that it was criticized by the Utah Supreme Court, which requires more concrete evidence of cause-in-fact before invoking that doctrine. Talbot v. Dr. W. H. Groves' Latter-Day Saints Hospital, Inc., 21 Utah 73, 440 P.2d 872 (1968). The res ipsa question is irrelevant when, as here, the plaintiff has produced ample evidence of the defendant's negligence. See Nixdorf v. Hicken, 612 P.2d 348, 352-353 (Utah 1980).

[150]The two experts in question, Dr. Karl Z. Morgan and Dr. Alice Stewart, have been of assistance to this court in this action as well, the former through testimony and scientific publications, the latter through publications of her significant epidemiological studies involving radiation. See Tr. at 2720-2883, 3207-3331 (testimony of Dr. Karl Z. Morgan); Morgan, "Tolerance Con-

centrations of Radioactive Substances," 51(4) J. Phys. and Colloid Chem. 984 (July 1947), PX-823; e.g., ———, "The Application of External and Internal Exposure Limits," 16 Am. Ind. Hyg. Assoc. Quarterly 307 (Dec. 1955), PX-660; e.g., Stewart & Kneale, "Radiation Dose Effects in Relation to Obstetric X-Rays and Childhood Cancers," The Lancet (June 6, 1970), PX-294B.

[151]See e.g., Kingston v. Chicago & N.W. Ry., 191 Wis. 610, 211 N. W. 913 (1927) (fire started by defendant's locomotive joins with fire of unknown origin, sweeps through plaintiff's property); Anderson v. Minneapolis, St. P. & S.S.M.Ry. Co., 146 Minn. 430, 179 N.W. 45 (1920) (locomotive sparks cause fire which burns plaintiff's property, soon followed by large fire of unknown origin; liability).

[152]See e.g., Baltimore & O. R.R. v Sulphur Springs Indep. School Dist., 96 Pa. 65 (1880) (railroad failed to maintain culverts in embankment; torrential rainfall carried away plaintiff's school house).

[153]Justice Traynor has explained the Summers burden-shifting approach as being "based on the policy that it is better to hold liable a negligent defendant who did not in fact cause the injury than to deny an innocent plaintiff any remedy when it cannot be determined which of the defendants is responsible for the harm but it appears that one of them was." Vasquez v. Alameda, 49 Cal. 2d 674, 682, 321 P.2d 1, 7 n. 2 (1958) (Traynor, J. dissenting).

[154]In both Summers and Ybarra as well, the initial burden of establishing a significant factual connection rested upon the plaintiff. Once the co-existing defendants and/or causes have reasonably been identified, the legal questions governing liability may be reached without further sifting. The burden shifted in Summers is that of proving by evidence that the conduct of defendant X does not belong among the "substantial factors" leading to imposition of liability.

[155]Use of any kind of "but-for" analysis—whether plaintiff's inju-

ry would not have occurred but for the conduct of the defendant—to determine factual causation is problematical at best; where likely "causes" co-exist, it is wholly inadequate to the task. W. Prosser, Handbook of the Law of Torts 239 (4th ed. 1971); Basko v. Sterling Drug, Inc., supra, 416 F.2d at 429. Whether defendant should be held liable for injuries which may well have occurred even in the absence of his conduct is a question concerning the appropriate scope of the law's protection, properly considered as part of the duty issue. See Part VII, supra; see also Thode, "The Indefensible Use of the Hypothetical Case to Determine Cause in Fact," 46 Texas L. Rev. 423 (1968).

Each of the cases cited by the Government in arguing for the applicability of "but for" analysis involve the more common A-collides-with-B type of causation problem; they are all motor vehicle accident cases. Watters v. Querry, 626 P.2d 445, 460 (Utah 1981); Taylor v. Silva, 615 P.2d 970, 971 (Nev. 1980); Zelman v. Stauder, 11 Ariz. App. 547, 466 P.2d 766, 768-769 (1970).

It is readily apparent that this is not an automobile accident case. It is equally apparent that the fact that the three courts use textbook proximates cause language in more routine cases does not in any way establish that they would use a "but for" analysis in a case in which it does not work. Indeed, in Watters v. Querry, the Utah Supreme Court approved jury instructions which read in part:

> The law does not necessarily recognize only one proximate cause of injury, consisting of only one factor, one act, or the conduct of only one person. . . .

Id., 626 P.2d at 460. In predicting as we must how state law would be applied to determine this case, this court has concluded that a Utah court faced with the same issues and upon the same record, would adopt the views set forth above, as would a court in Arizona or Nevada.

[156]Note, "Inapplicability of Traditional Tort Analysis," supra, 35 Stan. L. Rev. at 606 & n. 139, describes "causal linkages" as fact connections "which express a causal relationship that is solely statistical and not provably direct," and which "can be stated numerically as specific causation probabilities." See Calabresi,

"Concerning Cause and the Law of Torts. . . ," supra.

A statistical relationship is one type of factual connection that may be drawn between conduct and injury. It certainly is not the only one.

[157]See H.R. 1049, 96th Cong., 1st Sess. §§ 101-106 (1979); H.R. 3797, 96th Cong., 1st Sess. §§ 3211-3215 (1979); H.R. 5291, 96th Cong., 1st Sess. §§ 211-215 (1979).

[158]See S. 1480, 96th Cong., 2d Sess., § 4.

[159]See Pub.L. 96-510, Title III, § 301(e), Dec. 11, 1980, 94 Stat. 2767, 2805; 42 U.S.C. § 9651(e) (Supp. IV 1980).

[160]Strict, or "no-fault," liability as provided for in the proposed bills is not available under the Federal Tort Claims Act because of express statutory language. See Laird v. Nelms, 406 U.S. 797 (1972). Such an approach might be available under state law in cases involving private parties contaminating others with ultra-toxic materials.

[161]That reasonable people may differ in drawing inference from the same evidence "must be accepted as a necessary risk of the litigation process. That is the way of the courthouse. Any qualification that causal relation must be substantial or material is only a caution that the finding must rest on intelligent and reasonable considerations." Green, "The Causal Relation Issue in Negligence Law," 60 Mich. L. Rev. 543, 556 (1962); see also Anderson v. Minneapolis, St.P & S.Ste.M. Ry., 146 Minn. 430, 179 N.W. 45 (1920).

[162]Cf. the BEIR-III Report (1980), DX-1025, at 22: "on statistical grounds, however, the existence or nonexistence of a threshold dose is practically impossible to determine. . . ," esp. for very low doses because of the exponentially large study populations needed to demonstrate the relationship to a statistical certainty. Id., at 140; see J. Gofman, M.D., Radiation and Human Health 109-120 (1981), PX-1046 (description of an "ideal" low-dose epidemiological study).

[163]U.S. Atomic Energy Comm'n, "Some Effects of Ionizing Radiation on Human Beings: A Report of the Marshallese and Americans Accidentally Exposed to Radiation from Fallout. . . ," (July 1956), DX-642.

[164]R. Conard, M.D., et al., "Medical Survey of Rongelap People, March 1958, Four Years After Exposure to Fallout," Bookhaven Nat'l Laboratory (May 1959), DX-640.

[165]It is conceivable, for example, that a thyroid cancer induced by fallout from the 104-kt SEDAN test (July 6, 1962) with a 22-year latency period similar to the Marshallese experience would not even be yet detected or diagnosed.

[166]See e.g., J. Watson, Molecular Biology of the Gene 292-295 (2d ed. 1970); BIER-III Report, supra, DX-1025 at 25 references cited therein.

[167]See DX-1149, at 51; DX-1153 at 35; Part X supra.

[168]Delivery of radiation dosage at high rates may even result in a greater ratio of "kills"—cells lethally damaged by ionization—leaving proportionately fewer damaged cells per rad alive and potentially cancerous. See BEIR-III Report, supra, at 19-20, 23.

[169]Cancers of the thyroid and of the female breast are not necessarily fatal. As Radford's analysis indicated in 1980 the switch from cancer mortality data to cancer incidence data for such cancer more accurately describes the relevant dose-reponse relationship. See BIER-III Report, supra, at 250 (Statement of E. Radford, M.D.).

[170]See e.g, J. Gofman, Radiation and Human Health 43-44, 124-126 (1981), PX-1046; Parts III and IV, supra.

[171]See e.g., J. Reed, "Comparison of Fallout Doses from Nevada Tests (Revised)," TID-4500 (June 1960), PX-340/DX-766; H. Knapp, "Gamma Ray Exposure Dose to Non-Urban Populations from the Surface Deposition of Nuclear Test Fallout," TID-16457 (July 1962), PX-717.

[172]The defendant's motion to strike the testimony of the "human dosimeter" witnesses is denied. All other pending motions, unless otherwise dealt with in this opinion, are also denied.

[173]See P. Krey and H. Beck, "The Distribution Throughout Utah of ^{137}Cs and $^{239\&240}Pu$ from Nevada Test Site Detonations," EML-400 (Nov. 1981), DX-1108; Tr. at 4078-4147 (testimony of Philip W. Krey).

[174]See Tr. at 4803-4951 (testimony of Bruce W. Church); Tr. at 5661-5785 (testimony of Richard F. Smale); Tr. at 5785-5885 (testimony of F. Ward Whicker); Tr. at 5886-5967 (testimony of Dr. Lynn R. Anspaugh); DX-1118.

[175]See Transcripts of Proceedings, Meeting of the Dose Assessment Advisory Group, 1980-1982, DX-1008 through-1019.

[176]E.g., 2 Transcript of Proceedings, Meeting of the DAAG, Mar. 13, 1981, at 1-48, DX-1013.

[177]See generally, Transcripts of Proceedings, Meetings of the Dose Assessment Advisory Group 1980-1982, DX-1008 through-1019.

[178]See note 171, supra.

[179]See C. Johnson, M.D., "Cancer Incidence in an Area of Radioactive Fallout Downwind From the Nevada Test Site," 251 J. Am. Med. Assoc. 230 (Jan. 13, 1984), PX-1041B.

[180]Counting of fallout residues remaining even in stable soils for 25-30 years, e.g., the work of Beck and Kray, does not seem to account for the significant differences in exposure observed by monitors between measurements by one standing in the open as the fallout cloud passed through and readings of amounts left deposited on the ground itself. Cf. H. Beck and P. Kray, "External Radiation Exposure of the Population of Utah from Nevada Weapons Tests," EML-401 (January 1982), DX-1110; P. Kray and H. Beck, "The Distribution Throughout Utah of ^{137}Cs and $^{239\&240}Pu$ from Nevada Test Site Detonations," EML-400 (November 1981), DX-1008. That more cesium or plutonium

particles appear to have landed in northern Utah lawns does not conclusively demonstrate that persons much closer in time and geography to the rapidly decaying fallout clouds were less exposed. Even the contemporaneous monitoring data points significantly in the other direction.

[181]Even working from the axiom that all cancers may be caused by radiation, plaintiff's expert testimony states that fallout radiation could represent only a 20.4 percent contribution, 12.1% if medical irradiation is considered. Tr. at 3583-3584 (testimony of Dr. J. Gofman, M.D.).

[182]While some dispute as to diagnosis is reflected in the record, see Tr. at 5174-5176 (testimony of Dr. LeGrande C. Larsen, M.D.) the evidence preponderates in favor of the diagnosis listed here. See Tr. at 5263-5264, 5270 (testimony of Dr. John J. Murphy, M.D.).

[183]Testimony of plaintiff's expert, in light of the medical exposure indicated that "the fractional radiation causation from weapons test[s] is reduced to 21.5.

[184]Plaintiff's expert, using general calculations based upon the linear dose-response model, computed the "fractional causation due to weapons test radiation" to be 7.3 percent. Tr. at 3588 (testimony of Dr. John Gofman, M.D.).

[185]See C. Johnson, M.D. "Cancer Incidence in an Area of Radioactive Fallout Downwind From Nevada Test Site," 251 J. Am. Med. Assoc. 230 (Jan. 13, 1984), PX-1041B [note: all pending motions by plaintiffs and the Government to reopen the record for the purpose of offering additional articles and studies are granted.] This study is designated as the Johnson "survey" because the information was generated through questionnaire rather than direct study of medical records, etc. While some question has been raised concerning method, this court is satisfied that the work is of sufficient credibility to support its admissibility into evidence. See Tr. at 2926-3205, 3331-3384 (testimony of Dr. Carl Johnson): PX-1041 (draft, Johnson study).

[186]While the Johnson survey, for example, studies Utah Mormons rather than Nevadans such as Delsa Bradshaw, and trend would likely be consistent in both places. Pioche, Nevada, Mrs. Bradshaw's major place of residence during testing, apparently was bypassed by a number of the more significant fallout clouds. See DX-1118, ORERP fallout maps 1-14.

[187]This court is puzzled by estimates which calculate dose from alpha-emitters such as uranium and plutonium in terms of the entire lung mass when ionization by alpha particles is concentrated in short tracks through comparatively few cells. See J. Gofman, Radiation and Human Health 480-494 (1981), PX-1046. If, for example, the absorbed dose from alpha-emitters to the lung is 500 millirads if distributed over the entire mass of the adult lungs (approx. 1,000 grams), the dose to the 4 grams of epithelial cells lining the bronchial tubes—the cells actually absorbing the alpha energy—would seem to 1,000/4 2 0.500 mrad, or 125 rads to the actually exposed tissue. Compare id., 482-487. This hypothetical merely highlights a puzzle the court perceives in the ORERP technique. See e.g., Transcript of Fifth DAAG meeting, May 6, 1982, DX-1018 at 166, 203; see also UNSCEAR Report 1 135 at 149 (1977), PX-706/ DX-605.

[188]This court is also puzzled by the ORERP conclusion that neptunium-239 is the most significant radionuclide for calculation of inhalation exposure, while plutonium-239 is deemed "essentially insignificant," trailing 39 other nuclides including uranium-237 and -240 in importance. See Transcript of Fifth DAAG Meeting, May 6, 1982, DX-1018, at 165, 199. Neptunium-239, a beta emitter (decay energy = 0.723 MeV), decays with a half-life of 2.35 days into plutonium-239, an alpha-emitter (decay energy = 5.243 MeV) often of biological significance.

By the time that fallout dust particles might be resuspended by "dusty" work such as cattle-ranching, much of the "important" low-LET neptunium residue might have decayed into "insignificant" high-LET plutonium residue. Some tiny particles inhaled many escape the bronchial cleansing mechanisms, stay-

ing in the lungs for 500 days or longer, see Gofman, Radiation and Human Health, supra, at 481-482, allowing further decay.

Particularly where "silicosis" from inhalation of resuspended dust is proposed as an alternative "cause," see Tr. at 6419-6421 (testimony of Dr. Geno Saccomanno), calculated data concerning ground deposition of alpha-emitters by fallout is at times conspicuous because of its omission. See e.g., H. Hicks, Results of Calculations. . . Operation Upshot-Knothole, 1953, UCRL-53152 Pt. 4, (July 1981) DX-1163 (uranium, plutonium data deleted).

[189]From this figure, however, theoretical calculations of the fractional weapons test radiation causation yielded a figure of 10.6 percent. Tr. at 3573 (testimony of Dr. John Gofman).

[190]This conclusion is consistent with the opinion expressed by Dr. Charles Smart, cancer specialist and treating physician for Jeffrey Bradshaw. Tr. at 5368, 5370.

[191]Plaintiff's expert calculates the theoretical contribution from fallout exposure to be 15.0 percent for this case of cancer. Tr. at 3565 (testimony of John Gofman). However, an as yet unestablished synergistic relationship between the dietary factors and radiation could multiply the effective contribution by radiation several fold, id., at 3566-3568.

[192]E. Weiss, Leukemia Mortality in Southwestern Utah: 1950-1964," (Sept. 1965), PX-4.

[193]C. Heath, "Leukemia in Fredonia, Arizona," Memorandum, Aug. 4, 1966, PX-488; J. Crowell and C. Heath, "Leukemia in Parowan and Paragonah, Utah," memorandum, Apr. 26, 1967, PX-497; memorandum, C. Heath to Chief, Epidemiology Branch, CDC, July 5, 1961, PX-895; Letter from C. Heath to E. Weiss, Aug. 5, 1966, PX-905; see also PX-897.

[194]J. Lyon, et al., "Childhood Leukemias Associated With Fallout from Nuclear Testing," 300 New Eng. J. Med. 397-402 (Feb. 22, 1979), PX-7/DX-1000; J. Lyon, et. al., "Further Information on the Association of Childhood Leukemia with Atomic Fallout,"

(ca. 1980), PX-906; Tr. at 608-825, 662016668 (testimony of Dr. Joseph L. Lyon); PX-1061, 1062, 1063, 1064.

[195]If calculated from the series of highest exposure, UPSHOT-KNOTHOLE (1953) the latency periods in the four cases are 3, 11, and two 6-year periods. Some additional exposure was likely in 1952, 1955 and 1957 as well.

[196]See C. Land, et al., "Childhood Leukemia and Fallout from the Nevada Nuclear Tests," 223 Science 139-1 (Jan. 13, 1984), DX-1244; Tr. at 5079-5148 (testimony of Dr. Charles Land); but cf. Tr. at 5297-5406, (testimony of Dr. Charles R. Smart). See also, Viren, "An Alternative Analysis and Evaluation,. . . ," (1979), DX-81; Chernoff, "'Childhood Leukemia Associated with Fallout From Nuclear Testing': The Study and a Critique," attached to PX-388. But see letter from J. Lyon to C. Land, Feb. 1, 1979, PX-389; Letter from C. Land to J. Lyon, Feb. 9, 1979, PX-388; Tr. at 6620-6669 (testimony of Dr. Joseph L. Lyon).

[197]The testimony of the plaintiff's expert concerning fractional causation attributable to fallout radiation lends some additional support through estimates of 57.9, 41.3-75.5, and 70.5 percent contributions. Tr. at 3557-3561 (testimony of Dr. John Gofman).

[198]Gofman's fractional causation calculations project contributions from fallout radiation of 75.5 to 77.4 percent, based upon a theoretical dose of approximately 18 rads. Tr. at 3549-3556. Though higher than ORERP estimates, such an exposure was well within the realm of possibility—if not probability—in those communities.

This court is satisfied that the leukemia in the case of Arthur Bruhn was of a lymphatic type consistent with a possibility of causation by ionizing radiation.

[199]Gofman calculates the fractional causation in this case attributed to fallout radiation to be 33.9 percent, based upon a theoretical whole-body dose of 36.7 rads. Tr. at 3577.

[200]Gofman estimates the fractional causation due to fallout radiation in this case to be 47.5 percent, based on a theoretical dose of 36.7 rads. Tr. at 3590-3591.

[201]This case seems an appropriate one for the application of an old philosophical maxim known as Occam's Razor, which in essence states, "if everything in some science can be interpreted without assuming this or that hypothetical entity, there is no ground for assuming it." B. Russell, A History of Western Philosophy 472 (1972). Where the factual connections between radiation exposure and injury are as strong as the ones here, other largely hypothetical alternatives carry little force.

[202]Freedberg, et al., "The Pathologic Effects of I^{131} on the Normal Thyroid Gland of Man," 12 J. Clin. Endocrinology & Metabolism 1315-1349 (Oct. 1952) PX-625; Clark, "Association of Irradiation with Cancer of the Thyroid in Children and Adolescents," 159 J. Am. Med. Assoc. 1007 (Nov. 1975) PX-658; Gorbman, "Degenerative and Regenerative Changes in the Thyroid Gland Following High Doses of Radioactive Iodine," 2 Transactions of N. Y. Acad. Sci. 201-203 (Apr. 1949) PX-649; Goolden, "Carcinoma of the Thyroid Following Irradiation," British Med. J. 954 (Oct. 18, 1953), PX-618; Chapman, "The Use of Radioactive Iodine in the Diagnosis and Treatment of Hyperthyroidism: Ten Years' Experience," 34 Medicine J. Clin. Endocrinology & Metabolism 1383 (Nov. 1957) PX-624; Hempelmann, "Risk of Thyroid Neoplasms after Irradiation in Childhood," 160 Science 159 (Apr. 12, 1968), PX-822; ——, "Neoplasms in Youthful Populations Following X-Ray Treatment in Infancy," 1 Env. Research 338-58 (1967), PX-825; Silverman and Hoffman, "Thyroid Tumor Risk from Radiation of Diseases of the Thyroid Gland with the in vivo use of Radionuclides," 19 J. Nucl Med. 107 (Jan. 1978), DX-1176; Maxon, et al., "Clinically Important Radiation-Associated Thyroid Disease," 244 J. Am. Med. Assoc. 1802 (Oct. 17, 1980) DX-1178.

[203]Gofman calculated a theoretical "fractional radiation causation" in the case of Jacqueline Sanders of 84.5 percent, a higher figure than any other plaintiff. Tr. at 3594.

[204]That so many assumptions, "analogous" data from other times and places, and complex theoretical construction must play such a dominate role in dosimetry for off-site residents again highlights the negligent failure of the employees of the Govern-

ment to adequately measure actual exposure of real persons to real fallout radiation in the first place.

(THIS PAGE LEFT BLANK INTENTIONALLY)

APPENDIX "A"

Fission Product Decay Chains

TABLE 1.8. Decay chains and yields from thermal-neutron fission of U^{235}

Underlined numbers give experimental fission yields. Last fission yield along any chain usually represents total chain yield. Lower values for yields of earlier chain members may be caused by (1) direct formation in fission of later chain members, (21) chain branching, (3) experimental uncertainty. Latter accounts for cases where early chain member has higher yield than later one. Where branching occurs, arrows are shown only for decay modes observed experimentally; fraction in each branch is given where known. Parentheses indicate nuclide probably occurs but has not been observed. References for fission yields are cited following chains. Prepared by Dr. S. Katcoff from data available to 1960; Reprinted from *Nucleonics* 18, 201 (1960). Copright 1960 McGraw-Hill Publishing Company, Inc.

72. 47-hr Zn^{72} → 14.1-hr Ga^{72} → stable Ge^{72} (1, 2)
1.6×10^{-5}

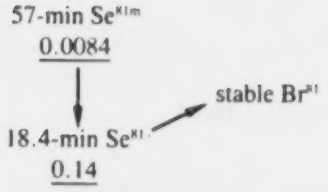
73. (2-min Zn^{73}) → 4.9-hr Ga^{73} → stable Ge^{73} (2)
1.1×10^{-4}

74. 7.8-min Ga^{74} → stable Ge^{74} (64)
0.00035

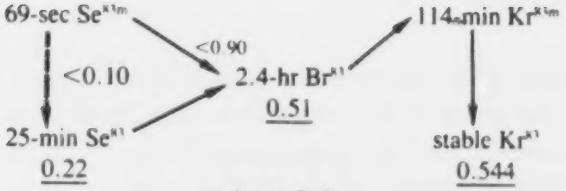
77. 54-sec GE^{77m} → 11.3-hr Ge^{77} (0.22); GE^{77m} → 38.7-hr As^{77} (0.78) → stable Se^{77} (3, 4)
0.0083; 0.0031

78. 2.1-hr Ge^{78} → 91-min As^{78} → stable Se^{78} (3, 4)
0.020 0.020

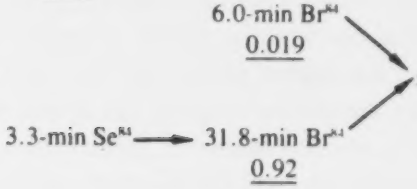
79. 9.0-min As^{79} → 3.89-min Se^{79m} → $\sim 6 \times 10^{5}$-yr Se^{79} → stable Br^{79} (5)
0.056

81. 

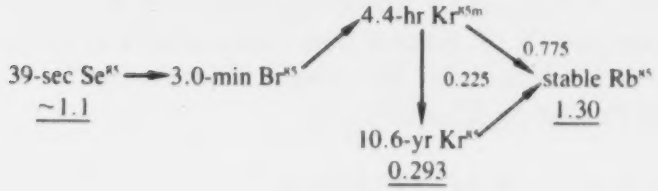
(6)

83. 

(7-11)

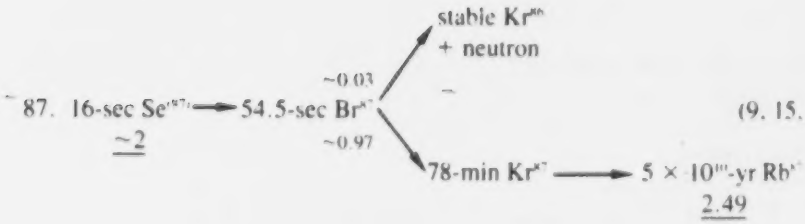
84. 

(9-12, 63)

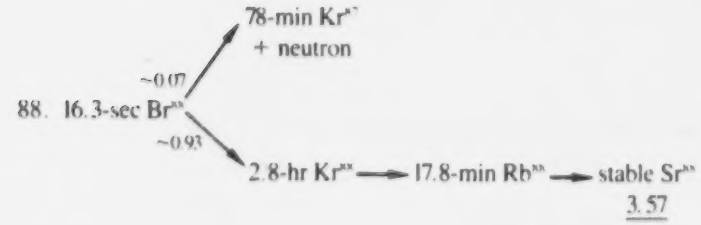
85. 

(9-11, 63)

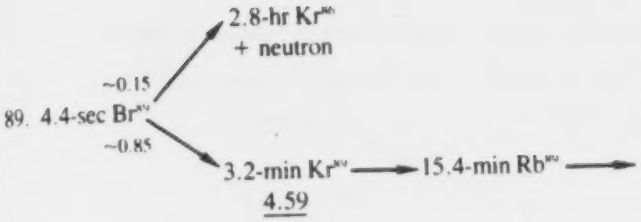
86. stable Kr^86
2.02
(9-11)

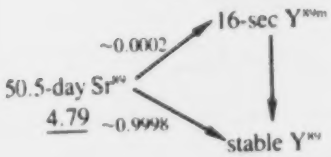
87. 

(9, 15, 63)

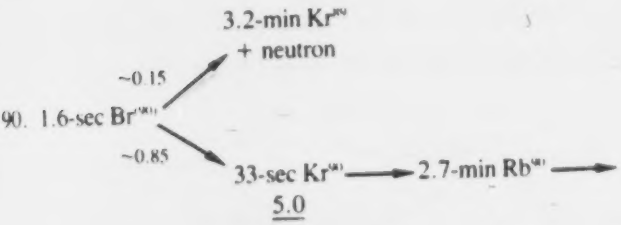
88. 

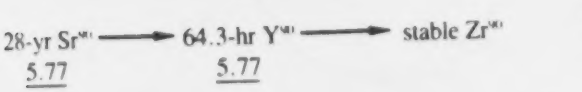
(9, 13)



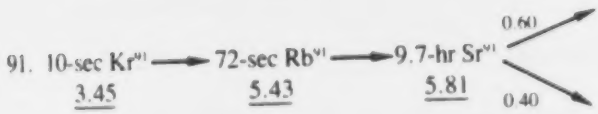


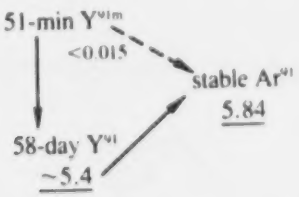
(14, 16, 17)





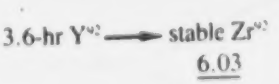
(9, 13, 14, 18, 19)





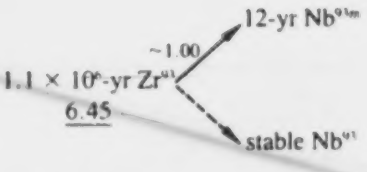
(13, 14, 17, 18, 19)





(13, 14, 20)

93. 2.0-sec Kr^{91} → 5.6-sec Rb^{91} → 7.9-min Sr^{91} → 10.3-hr Y^{91}
0.48 6.1

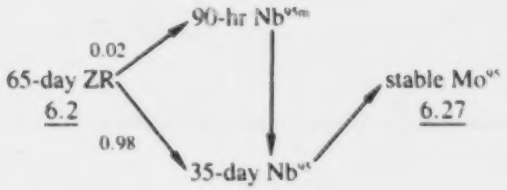


(13, 14, 62)

94. 1.4-sec Kr^{94} → 2.9-sec Rb^{94} → 1.3-min Sr^{94} →
0.10

20-min Y^{94} → stable Zr^{94} (13, 14, 21)
5.4 6.40

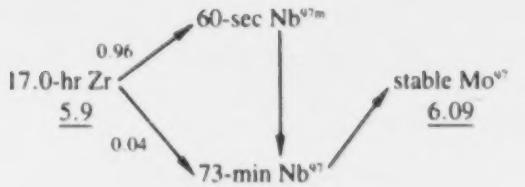
95. short Kr^{95} → (short Rb) → 40-sec Sr^{95} → 10-min Y^{95} →
0.007



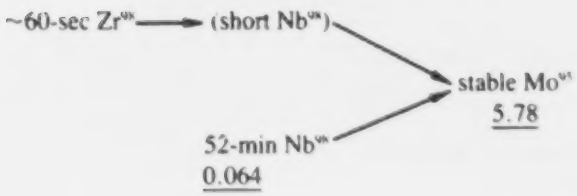
(13, 14, 22)

96. stable Zr^{96} (13)
6.33

97. (short Kr^{97}) → (short Rb) → (short Sr) → (short Y) →
$<6 \times 10^{-5}$



(13, 14, 16, 22)



98. (13)

99. 33-sec Zr^{99} → 2.4-min Nb^{99} → 66.5-hr Mo^{99} (0.87 / 0.13)
6.06

6.0-hr Tc^{99m} → stable Ru^{99}
2.1 × 10^5-yr Tc^{99} → stable Ru^{99} (16, 23)

100. 3.0-min Nb^{100} → stable Mo^{100} (13)
6.30

101. 1.0-min Nb^{101} → 14.6-min No^{101} → 14.0-min Tc^{101} → stable Ru^{101} (13, 24)
~5.6 5.0

102. 11.5-min No^{102} → 4.1-min Tc^{102} / 5-sec Tc^{102} → stable Ru^{102} (13, 24)
~4.3 4.1

103. 1.2-min Tc^{103} → 39.7-day Ru^{103} → 57-min Rh^{103m} (0.995) / stable Rh^{103} (0.005) (25)
3.0

104. (<2.5-min Mo^{104}) → 18-min Tc^{104} → stable Ru^{104} (13)
1.8

105. (<2-min Mo^{105}) → 9-min Tc^{105} → 4.45-hr Ru^{105} →
0.9

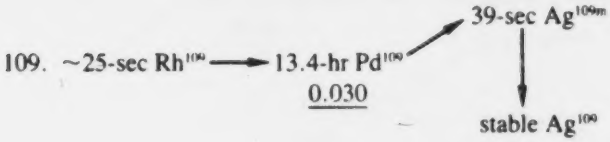
38-sec Rh^{105m}
36-hr Rh^{105} → stable Pd^{105} (24, 26)

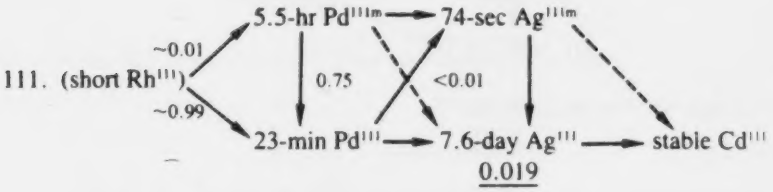
106. 1.01-yr Ru^{106} → 29-sec Rh^{106} → stable Pd^{106} (13, 25)
0.38

107. (<1-min Tc^{107}) → 4.6-min Ru^{107} → 45-sec Rh^{107m} / 22-min Rh^{107}
0.19

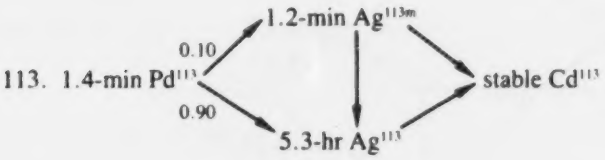
7 × 10^6-yr Pd^{107} stable Ag^{107} (27)

108. (<1-min Tc^{108}) → 4.3-min Ru^{108} → 18-sec Rh^{108} → stable Pd^{108}

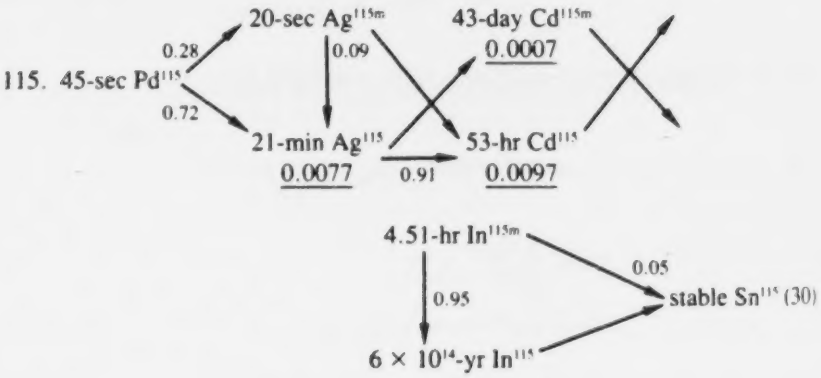




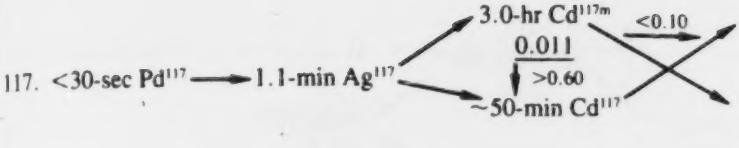
112. 21-hr Pd^{112} → 3.2-hr Ag^{112} → stable Cd^{112} (28, 29)
0.010

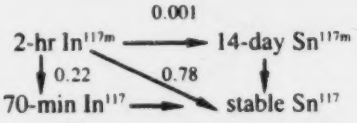


114. 2.4-min Pd^{114} → 5-sec Ag^{114} → stable Cd^{114}

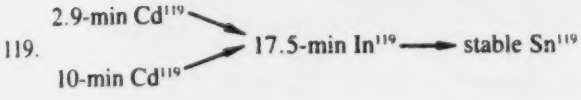


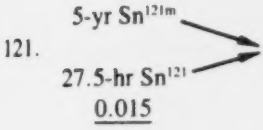
116. <30-sec Pd^{116} → 2.5-min Ag^{116} → stable Cd^{116}



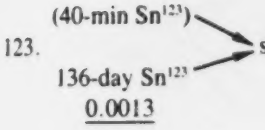


(31)

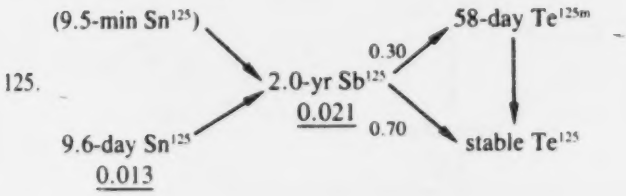




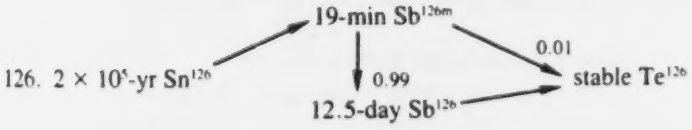
(32)

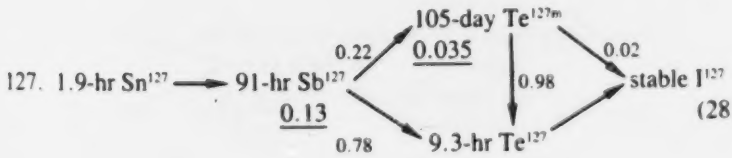


(33)

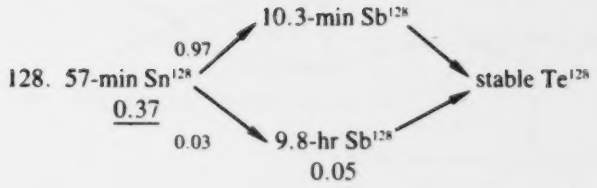


(34-36)

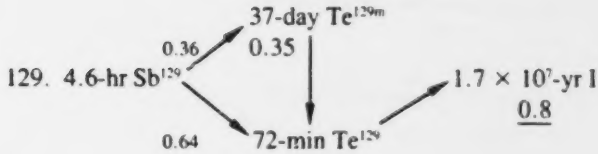




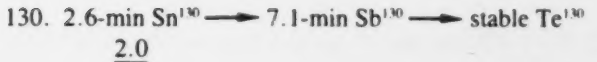
(28, 37, 38)



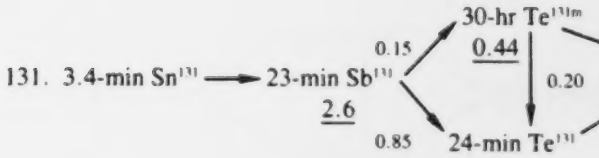
(27)

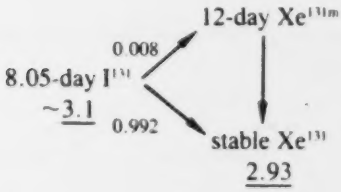


(37,39)

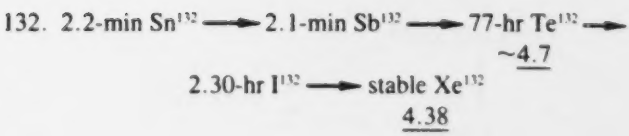


(40)

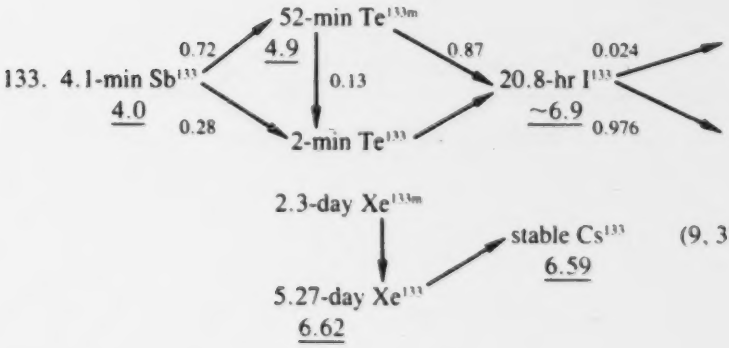




(11, 28, 37, 40, 41, 44)



(11, 37, 44)



(9, 37, 42, 44)

134. (50-sec Sb^{134}) → 43-min Te^{134} → 52.5-min I^{134} →
6.9 7.8
Stable Xe^{134}
8.06
(11, 37, 43, 44)

135. (<0.5-min Te^{135}) → 6.7-hr I^{135}
6.1
0.30 → 15.3-min Xe^{135m}
0.70 → 9.2-hr Xe^{135}
6.3
2.6 × 10^6-yr Cs^{135} → stable Ba^{135}
6.41
(9, 37, 42, 45-47)

136. 86-sec I^{136} → stable Xe^{136}
3.1 6.46
(11, 48)

137. 24.4 sec I^{137}
~0.04 → stable Xe^{136} + neutron
~0.96 → 3.9-min Xe^{137} → 30-yr Cs^{137}
6.00 6.15
0.92 → 2.57-min Ba^{137m}
0.08 → stable Ba^{137}
(9, 49)

138. 6.3-sec I^{138}
~0.03 → 3.9-min Xe^{137} + neutron
~0.97 → 17-min Xe^{138} → 32.2-min Cs^{138} → stable Ba^{138}
5.49 5.74
(13, 50)

139. 2.0-sec I^{139}
~0.04 → 17-min Xe^{138} + neutron
~0.96 → 41-sec Xe^{139} → 9.5-min Cx^{139} →
5.4 6.47
83-min Ba^{139} → stable La^{139}
6.55
(14, 16, 17)

140. 16-sec Xe^{140} → 66-sec Cs^{140} → 12.8-day Ba^{140} →
3.8 6.0 6.35
40.2-hr La^{140} → stable Ce^{140}
6.35 6.44
(14, 16, 51, 52, 65)

141. 1.7-sec Xe^{141} ⟶ 25-sec Cs^{141} ⟶ 18-min Ba^{141} ⟶
1.33 4.6 6.3

3.8-hr La^{141} ⟶ 33-day Ce^{141} ⟶ stable Pr^{141} (14, 17
6.4 ~6.0 53, 54)

142. ~1.5-sec Xe^{142} ⟶ <8-sec Cs^{142} ⟶ 10-min Ba^{142} ⟶
0.35

81-min La^{142} ⟶ stable Ce^{142} (9, 13, 65, 66)
6.01

143. 1-sec Xe^{143} ⟶ (short Cs) ⟶ 13-sec Ba ⟶ 18-min La^{143} ⟶
0.051

33-hr Ce^{143} ⟶ 13.7-day Pr^{143} ⟶ stable Nd^{143} (9, 13, 14, 55, 65)
6.0 6.03

144. short Xe^{144} ⟶ (short Cs) ⟶ (short Ba) ⟶ (short La)
0.006

280-day Ce^{144} ⟶ 17.4-min Pr^{144} ⟶ 5 × 10-yr Nd^{144}
~6.0 5.62 (9, 13, 14, 65)

145. 3.0-min Ce^{145} ⟶ 5.96-hr Pr^{145} ⟶ stable Nd^{145} (9, 13, 65)
3.98

146. 13.9-min Ce^{146} ⟶ 24.4-min Pr^{146} ⟶ stable Nd^{146} (9, 13, 65)
3.07

147. 1.2-min Ce^{147} ⟶ 12.0-min Pr^{147} ⟶ 11.1-day Nd^{147} ⟶
~2.7

2.6-yr Pm^{147} ⟶ 1.3 × 10^{11}-yr Sm^{147} (9, 56, 65)
2.36

148. 40-sec Ce^{148} ⟶ 1.95-min Pr^{148} ⟶ stable Nd^{148} (9, 13, 65)
1.71

149. (2.0-hr Nd^{149}) ⟶ 53.1-hr Pm^{149} ⟶ stable Sm^{149} (9, 56, 65)
1.13

150. stable Nd^{150} (9, 13, 65)
0.67

151. (13-min Nd^{151}) 28.4-hr Pm^{151} 80-yr Sm^{151} stable Eu^{151}
0.44 (9, 65)

152. stable Sm^{152} (9, 65)
0.281

153. 47-hr Sm^{153} → stable Eu^{152} (28, 57, 65)
0.15 0.169

154. stable Sm^{154} (9, 65)
0.077

155. 24-min Sm^{155} → 4-yr Eu^{155} → stable Gd^{155} (58, 59, 65)
0.033 0.033

156. 9-hr Sm^{156} → 15.4-day Eu^{156} → stable Gd^{156} (28, 57, 59)
0.013 0.014

157. 15.4-hr Eu^{157} → stable Gd^{157} (60)
0.0078

158. 60-min Eu^{158} → stable Gd^{158} (60)
0.002

159. 18.0-hr Gd^{159} → stable Tb^{159} (57, 61)
0.00107

161. (3.7-min Gd^{161}) 6.9-day Tb^{161} → stable Dy^{161} (57, 61)
7.6×10^{-5}

166. 82-hr Dy^{166} → 27.3-hr Ho^{166} → stable Er^{166}

1. C. D. Coreyell and N. Sugarman, editors, "Radiochemical Studies: The Fission Products," *Nat. Nucl. Energ. Ser.* IV-9 (New York: McGraw-Hill Book Co., Inc. 1951).
2. J. M. Siegal and L. E. Glendenin, Ref. 1, p. 549.
3. E. P. Steinberg and D. W. Engelkemeir, Ref. 1, p. 566.
4. N. Sugarman, *Phys. Rev.* **89**, 570 (1953).
5. J. G. Cunninghame, *Phil. Mag.* **44**, 900 (1953).
6. L. E. Glendenin, Ref. 1, p. 596.
7. L. E. Glendenin, Ref. 1, Editors' Note, p. 591.
8. J. R. Arnold and N. Sugarman, *J. Chem. Phys.* **15**, 703 (1947).
9. J. A. Petruska, *et al.*, *Can. J. Phys.* **33**, 693 (1955).
10. A. T. Blades, H. G. Thode, *Z. Naturforsch.* **10a**, 838 (1955).
11. A. T. Blades, *et al.*, *Can J. Chem.* **34**, 233 (1956).
12. J. E. Sattizahn, *et al.*, *Bull. Am. Phys. Soc. II*, **2**, 197 (1957).

13. L. E. Glendenin, *et al.*, quoted by E. P. Steinberg and L. E. Glendenin in *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy* **7**, p. 3 (United Nations, New York, 1956).

14. A. C. Wahl, *J. Inorg. Nucl. Chem.* **6**, 263 (1958). Also private communication from A. C. Wahl, Sept., 1960, and Ph.D. theses from Washington University, St. Louis (1959) by R. L. Ferguson, D. E. Troutner, D. R. Nethaway, K. Wolfsberg. Measured fractional cumulative yields of short-lived rare gases and independent yields of several other fission products.

15. A. F. Stehney and N. Sugarman, *Phys. Rev.* **89**, 194 (1953).

16. G. W. Reed and A. Turkevich, *Phys. Rev.* **92**, 1473 (1953).

17. A. P. Baerg and R. M. Bartholomew, *Can. J. Cham.* **35**, 980 (1957).

18. G. W. Reed, *Phys. Rev.* **98**, 1327 (1955).

19. W. E. Grummitt and G. M. Milton, *J. Inorg. Nucl. Chem.* **5**, 93 (1957).

20. E. J. Hoagland and S. Katcoff, Ref. 1, p. 660.

21. C. R. Dillard, *et al.*, Ref. 1, 692.

22. C. D. Coryell *et al.*, *Phys. Rev.* **77**, 755 (1950).

23. J. Terrell, *et al.*, *Phys. Rev.* **92**, 1091 (1953).

24. D. R. Wiles and C. D. Coryell, *Phys. Rev.* **96**, 696 (1954).

25. W. H. Hardwick, *Phys. Rev.* **92**, 1072 (1953).

26. W. H. Sullivan, *et al.*, Ref. 1, p. 808.

27. C. D. Coryell and J. W. Winchester, Progress Report, Laboratory for Nuclearn Science, MIT (Aug. 31, 1955).

28. D. W Engelkemeir, *et al.*, Ref. 1, p. 1372.

29. J. A. Seiler, Ref. 1, p. 860.

30. A. C. Wahl and N. A. Bonner, *Phys. Rev.* **85**, 570 (1952).

31. R. P. Metcalf, Ref. 1, p. 905.

32. E. P. Steinberg, Ref. 1, Editors' Note, p. 913.

33. G. R. Leader, Ref. 1, p. 919.

34. J. A. Seiler, Ref. 1, p. 910.

35. C. W. Stanley and L. E. Glendenin, Ref. 1, p. 947.

36. G. R. Leader and W. H. Sullivan, Ref. 1, p. 934.

37. A. C. Pappas, Technical Report No. 63, Laboratory for Nuclear Science, MIT (Sept., 1953).

38. L. E. Glendenin, Ref. 1, Editors' Note, p. 979.

39. B. C. Purkayastha, G. R. Martin, *Can. J. Chem.* **34**, 293 (1956).

40. A. C. Pappas and D. R. Wiles, *J. Inorg. Nucl. Chem.* **2**, 69 (1956).

41. R. M. Bartholomew, *et al.*, *Can. J. Chem.* **31**, 120 (1953).

42. S. Katcoff, W. Rubinson, *Phys. Rev.* **91**, 1458 (1953).

43. L. Yaffe, *et al.*, *Can. J. Chem.* **31**, 48 (1953).

44. A. C. Wahl, *Phys. Rev.* **99**, 730 (1955).

45. L. E. Glendenin, R. P. Metcalf, Ref. 1, p. 992.

46. S. Katcoff, *et al.*, Ref. 1, p. 1005.

47. F. Brown, L. Yaffe, *Can. J. Chem.* **31**, 242 (1953).

48. C. W. Stanley and S. Katcoff, *J. Chem. Phys.* **17**, 653 (1949).

49. F. Brown, *J. Inorg. Nucl. Chem.* **1**, 248 (1955).

50. R. M. Bartholomew and A. P. Baerg, *Can. J. Chem.* **34**, 201 (1956).

51. The value 6.44 is an average of 6.33 and 6.56 from Refs. 9 and 13, respectively. It is assumed that these mass-spectrometric measurements on Ce^{140} are also accurate measures of the yield of Ba^{140} since independent yields of La^{140} and Ce^{140} are very small (Ref. 19). Many fission yields have been determined relative to Ba^{140}: these are now normalized to yield of 6.44 for the latter. Absolute radiochemical measurements of Ba^{140}, Refs. 16 and 52, average 6.35.

52. L. Yaffe, *et al.*, *Can. J. Chem.* **32**, 1017 (1954); D. C. Santry and L. Yaffe, *Can. J. Chem.*, **38**, 464 (1960).

53. W. H. Burgus and N. E. Ballou, Ref. 1, p. 1184.

54. G. P. Ford. C. W. Stanley, AECD-3551 (1953).

55. S. Katcoff, *et al.*, Ref. 1, p. 1167.

56. J. A. Marinsky and L. E. Glendenin, Ref. 1, p. 1229 and p. 1254.

57. H. G. Petrow and G. Rocco, *Phys. Rev.* **96**, 1614 (1954).

58. L. Winsberg. Ref. 1. p. 1284.

59. L. Winsberg, Ref. 1, p. 1302 and p. 1311.

60. L. Winsberg, Ref. 1, p. 1292.

61. E. C. Freiling, *et al.*, *Phys. Rev.* **96**, 102 (1954).

62. J. D. Knight, *et al.*, *J. Inorg. Nucl. Chem.* **10**, 183 (1959).

63. J. E. Sattizahn, et al., J. Inorg. Nucl. Chem. **12**, 206 (1960).

64. J. A. Marinsky and E. Eichler, *J. Inorg. Nucl. Chem.* **12**, 223 (1960).

65. Y. Y. Chu, *UCRL-8926* (1959).

66. K. Wolfsbert, *et al.*, *J. Inorg. Nucl. Chem.* **12**, 201 (1960).

Table 1.8 presents a summary of fission product decay chains and yields for slow, or "thermal" neutron fission of ^{235}U. It represents a comprehensive review of all data published by 1960, and available to those who in prior years were responsible for estimating the risks arising from detonation of nuclear fission devices. While some specific data have since been modified in light of more accurate measurement, e.g., the half-life of ^{89}Sr is now listed as 52 days rather than 50.5 days, the Table provides a compendium of information contemporaneous to atmospheric testing.

The same chains of fission products appear in the fission of other nuclei, e.g., ^{233}U, ^{239}Pu, but with different yields than those given above. Fission involving fast neutrons (E_n ~0.4 – 7 MeV), as in the detonation of a nuclear fission device will also result in fission product yields somewhat different from those produced in fission by thermal neutrons (E_n ~0.025 eV). See Table 1.10 and Figs. 1.35 and 1.37, infra. The similarities predominate.

From: 3 E. Hyde, The Nuclear Properties of the Heavy Elements: Fission Phenomena 87-111 (1971 ed.); see also id., at 141 et seq.

TABLE 1.10. Thermal-neutron fission yields (per cent) from U^{233}, U^{235}, and Pu^{239}.

Fission product	U^{233}	U^{235}	Pu^{239}
47-hr Zn^{72}		1.6×10^{-5}	1.2×10^{-4}
4.9-hr Ga^{73}		1.1×10^{-4}	
7.8-min Ga^{74}		3.5×10^{-4}	
11.3-hr Ge^{77}	0.011	0.0031	
38.7-hr As^{77}	0.021	0.0083	
2.1-hr Ge^{78}		0.020	
91-min As^{78}		0.020	
9.0-min As^{79}		0.056	
total Br^{80}	3.9×10^{-4}	1.0×10^{-5}	
57-min Se^{81m}		0.0084	
18.4-min Se^{81}		0.14	
35.9-hr Br^{82}	1.1×10^{-3}	4×10^{-5}	
25-min Se^{83}		0.22	
2.4-hr Br^{83}	0.87	0.51	0.084
stable Kr^{83}	1.17	0.544	0.29
6.0-min Br^{84}		0.019	
31.8-min Br^{84}		0.92	
stable Kr^{84}	1.95	1.00	0.47
39-sec Se^{85}		~1.1	
10.6-yr Kr^{85}	0.58	0.293	0.127
stable Rb^{85}	2.51	1.30	0.539
stable Kr^{86}	3.27	2.02	0.76
9.7-hr Sr^{91}	5.57	5.81	2.43
58-day Y^{91}	5.1	~5.4	2.9
stable Zr^{91}	6.43	5.84	2.61
2.7-hr Sr^{92}		5.3	
stable Zr^{92}	6.64	6.03	3.14
10.3-hr Y^{92}		6.1	
1.1×10^{6}-yr Zr^{93}	6.98	6.45	3.97
stable Zr^{94}	6.68	6.40	4.48
65-day Zr^{95}	6.1	6.2	5.8
stable Mo^{95}	6.11	6.27	5.03
stable Zr^{96}	5.58	6.33	5.17
23-hr Nb^{96}	6.5×10^{-3}	6.1×10^{-4}	3.6×10^{-3}
17.0-hr Zr^{97}		5.9	5.5
stable Mo^{97}	5.37	6.09	5.65
52-min Nb^{98}	0.20	0.064	0.20
stable Mo^{98}	5.15	5.78	5.89
66.5-hr Mo^{99}	4.80	6.06	6.10
stable Mo^{100}	4.41	6.30	7.10
stable Ru^{101}	2.91	5.0	5.91
stable Ru^{102}	2.22	4.1	5.99
39.7-day Ru^{103}	1.8	3.0	5.67
stable Ru^{104}	0.94	1.8	5.93

TABLE 1.10. (Continued)

Fission product	U^{233}	U^{235}	Pu^{239}
18.6-day Rb^{86}	2.3×10^{-4}	2.9×10^{-5}	2.3×10^{-5}
16-sec Se^{87}		~2	
5×10^{10}-hr Rb^{87}	4.56	2.49	0.92
stable Sr^{88}	5.37	3.57	1.42
50.5-day Sr^{89}	5.86	4.79	1.71
28-yr Sr^{90}	6.43	5.77	2.25
21.0-hr Pd^{112}	0.016	0.010	0.12
43-day Cd^{115m}	0.0011	0.0007	0.0031
53-hr Cd^{115}	0.020	0.0097	0.0038
total 115	0.021	0.0104	0.041
3.0-hr Cd^{117m}			
0.011			
13-day Cs^{136}			
0.12			
0.0068			
0.11			
27.5-hr Sn^{121}	0.018	0.015	0.043
136-day Sn^{123}		0.0013	
9.6-day Sn^{125}	0.052	0.013	0.071
2.0-yr Sb^{125}		0.021	
91-hr Sb^{127}	0.60	0.13	0.39
4.45-hr Ru^{105}		0.9	
36-hr Rh^{105}			3.9
1.01-yr Ru^{106}	0.24	0.38	4.57
22-min Rh^{107}		0.19	
13.4-hr Pd^{109}	0.044	0.030	1.40
7.6-day Ag^{111}	0.024	0.019	0.23
9.2-hr Xe^{135}		6.3	
2.6×10^6-hr Cs^{135}	6.03	6.41	7.17
86-sec I^{136}	1 8	3.1	2.1
stable Xe^{136}	6.63	6.46	6.63
30-yr Cs^{137}	6.58	6.15	6.63
stable Ba^{138}		5.74	6.31
83-min Ba^{139}	6.45	6.55	5.87
12-8-day Ba^{140}	5.4	6.35	5.4
stable Ce^{140}	6.47	6.44	5.60

105-day Te^{127m}		0.035	
57-min Sn^{128}		0.37	
25.0-min I^{128}		3×10^{-5}	
37-day Te^{129m}		0.35	
1.7×10^{7}-yr I^{129}		0.8	
2.6-min Sn^{130}		2.0	
12.6-hr I^{130}		5×10^{-4}	
30-hr Te^{131m}		0.44	
8.05-day I^{131}	2.9	~3.1	3.77
stable Xe^{131}	3.39	2.93	3.78
77-hr Te^{132}	4.4	~4.7	5.1
stable Xe^{132}	4.64	4.38	5.26
20.8-hr I^{133}		~6.9	5.2
5.27-day Xe^{133}		6.62	6.91
stable Cs^{133}	5.78	6.59	6.91
52.5-min I^{134}		7.8	
stable Xe^{134}	5.95	8.06	7.47
6.7-hr I^{135}	5.5	6.1	5.7
stable Sm^{152}	0.220	0.281	0.62
47-hr Sm^{153}	0.11	0.15	0.37
stable Eu^{153}	0.13	0.169	
stable Sm^{154}	0.045	0.077	0.29
24-min Sm^{155}		0.033	0.23
4-yr Eu^{155}		0.033	

3.8-hr La^{141}	7.1	6.4	5.7
33-day Ce^{141}		~6.0	5.1
stable Pr^{141}	6.4		(4.5)*
stable Ce^{142}	6.83	6.01	5.01
33-hr Ce^{143}		5.7	5.3
stable Nd^{143}	5.99	6.03	4.57
280-day Ce^{144}	4.5	~6.0	3.79
5×10^{15}-hr Nd^{144}	4.61	5.62	3.93
stable Nd^{145}	3.47	3.98	3.13
stable Nd^{146}	2.63	3.07	2.60
11.1-day Nd^{147}		~2.7	2.2
2.6-yr Pm^{147}	1.9		1.94
1.3×10^{11}-yr Sm^{147}	1.98	2.36	2.07
stable Nd^{148}	1.34	1.71	1.73
53.1-hr Pm^{149}			1.4
stable Sm^{149}	0.76	1.13	1.32
stable Nd^{150}	0.56	0.67	1.01
80-yr Sm^{151}	0.335	0.44	0.80
15.4-day Eu^{156}	0.011	0.014	0.11
15.4-hr Eu^{157}		0.0078	
60-min Eu^{158}		0.002	
18.0-hr Gd^{159}		0.00107	0.021
6.9-day Tb^{161}		7.6×10^{-5}	0.0039
82-hr Dy^{166}			6.8×10^{-5}

Reprinted from S. Katcoff, *Nucleonics* **18**, No. 11, p. 203, Copyright 1960 (New York: McGraw-Hill Publishing Co., Inc.).

U^{233}. Yields from U^{233} for stable and longer-lived radioactive nuclides are derived from D. R. Bidinosti, D. E. Irish, and R H. Tomlinson, *Chalk River Symposium on Nuclear Chemistry*, September 1960 *and Can. J. Chem.* **39**, 628 (1961).; M. P. Anikina, *et al.*, in *Proceedings of Second International Conference on the Peaceful Uses of Atomic Energy* **15**, p. 446 (New York: United Nations, 1959); E. P. Steinberg, *et al.*, *Phys. Rev.***95**, 867 (1954); W. Fleming, *et al.*, *Can. J. Phys.* **32**, 522 (1954); E. A. Melaika, *et al.*, *Can. J. Chem.* **33**, 830 (1955).

Radiochemically determined yields: D. C. Santry and L. Yaffe, *Can. J. Chem.* **38**, 421 (1960); R. M. Bartholomew, *et al.*, *Can. J. Chem* **37**, 660 (1959); E. P. Steinberg and L. E. Glendenin, in *Proceedings of First International Conference on the Peaceful Uses of Atomic Energy* **7**, p. 3 (New York: United Nations, 1956).

U^{235}. See reference for Table 1.8.

Pu^{239}. Yields from Pu^{239} for stable and longer-lived radioactive nuclides are derived from H. R. Fickel and R. H. Tomlinson, *Can. J. Phys.* **37**, 916, 926 (1959); K. Fritze, et al., in *Proceedings of Second International Conference on the Peaceful Uses of Atomic Energy*, **15**, p. 436; M. P. Anikina, *et al.*, *op cit.*; D. M. Wiles, *et al.*, *Can. J. Chem.* **34**, 193 (1956).

Radiochemically determined yields: L. R. Bunney, *et al.* in Proceedings of Second International Conference on the Peaceful Uses of Atomic Energy **15**, p. 444; R. M. Bartholomew, *et al.*, *op. cit.*; G. P. Ford, *et al.*, LA-1997 (1956); E. P. Steinberg, M. S. Freedman in "Radio-chemical Studies: The Fission Products," C. D. Coryell, N. Sugarman, eds., NNES IV-9, 1378 (New York: McGraw-Hill, 1951).

No. C 79-0515-1

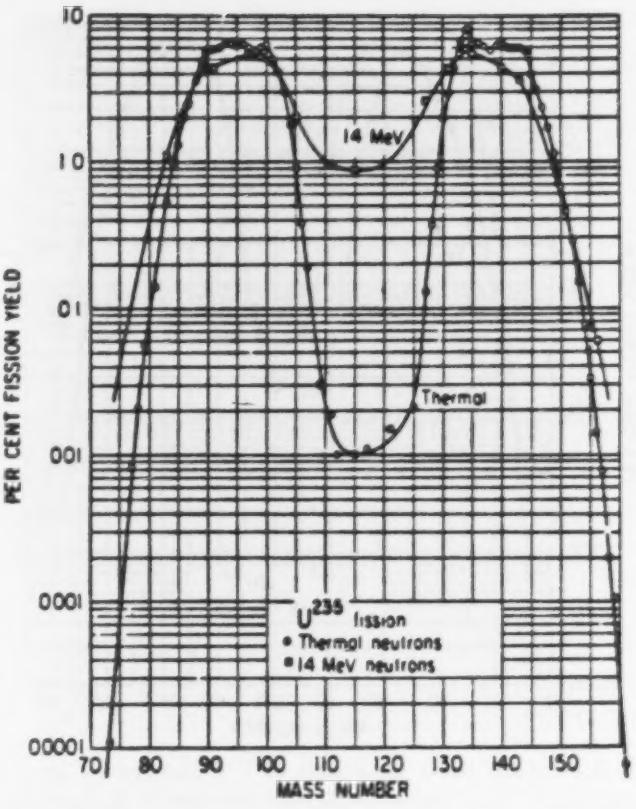


FIG. 1.37. The mass yield curves for the slow neutron-induced fission of U^{233} and Pu^{239}. Prepared by S. KATCOFF.

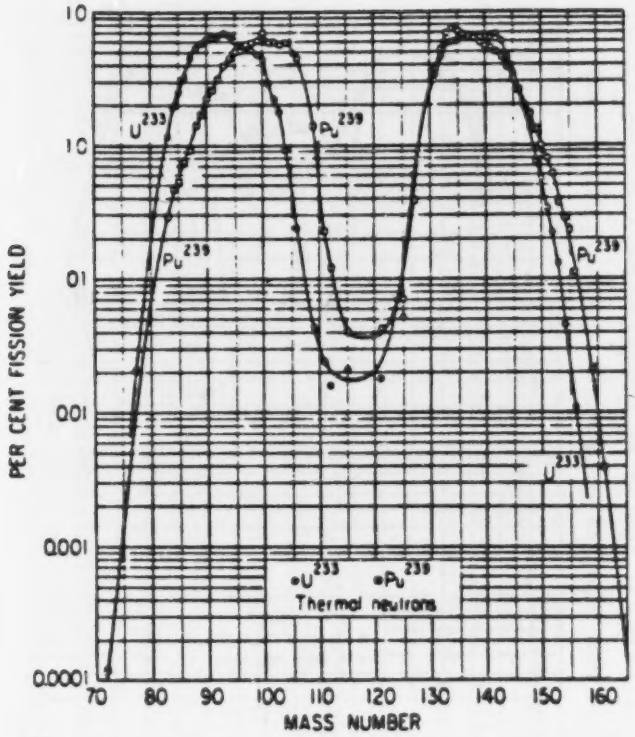


FIG. 1.35. Yield-mass curve for fission of U^{235} induced by slow neutrons. Curves plotted from "best" values taken from literature by S. KATCOFF.

(THIS PAGE LEFT BLANK INTENTIONALLY)

(THIS PAGE LEFT BLANK INTENTIONALLY)

APPENDIX "B"

TABLE OF NTS NUCLEAR TEST SERIES AND EVENTS

Event	Date	Time	Yield	Type
		Operation RANGER		
ABLE	1/27/51	5:45 a.m. PST	1 kt	1,060 ft. airdrop
BAKER	1/28/51	5:52 a.m. PST	8 kt	1,080 ft. airdrop
EASY	2/01/51	5:47 a.m. PST	1 kt	1,080 ft. airdrop
BAKER-2	2/02/51	5:49 a.m. PST	8 kt	1,100 ft. airdrop
FOX	2/06/51	5:47 a.m. PST	22 kt	1,435 ft. airdrop
		Operation BUSTER		
ABLE	10/22/51	6:00 a.m. PST	0.1 kt	100 ft. tower
BAKER	10/28/51	7:20 a.m. PST	3.5 kt	1,118 ft. airdrop
CHARLIE	10/30/51	7:00 a.m. PST	14 kt	1,312 ft. airdrop
DOG	11/01/51	7:30 a.m. PST	21 kt	1,417 ft. airdrop
EASY	11/05/51	8:30 a.m. PST	31 kt	1,314 ft. airdrop
		Operation JANGLE		
SUGAR	11/19/51	9:00 a.m. PST	1.2 kt	3.5 ft. surface
UNCLE	11/29/51	12:00 noon PST	1.2 kt	17 ft. underground
		Operation TUMBLER-SNAPPER		
ABLE	4/01/52	9:00 a.m. PST	1 kt	793 ft. airdrop
BAKER	4/15/52	9:30 a.m. PST	1 kt	1,109 ft. airdrop
CHARLIE	4/22/52	9:30 a.m. PST	31 kt	3,447 ft. airdrop
DOG	5/01/52	8:30 a.m. PST	19 kt	1,040 ft. airdrop
EASY	5/07/52	4:15 a.m. PST	12 kt	300 ft. tower
FOX	5/25/52	4:00 a.m. PST	11 kt	300 ft. tower
GEORGE	6/01/52	3:55 a.m. PST	15 kt	300 ft. tower
HOW	6/05/52	3:55 a.m. PST	14 kt	300 ft. tower
		Operation UPSHOT-KNOTHOLE		
ANNIE	3/17/53	5:20 a.m. PST	16 kt	300 ft. tower
NANCY	3/24/53	5:10 a.m. PST	24 kt	300 ft. tower
RUTH	3/31/53	5:00 a.m. PST	0.2 kt	304.7 ft. tower
DIXIE	4/06/53	7:30 a.m. PST	11 kt	6,022 ft. airdrop
RAY	4/11/53	4:45 a.m. PST	0.2 kt	100 ft. tower
BADGER	4/18/53	4:35 a.m. PST	23 kt	300 ft. tower
SIMON	4/25/53	4:30 a.m. PST	43 kt	300 ft. tower
ENCORE	5/08/53	7:30 a.m. PST	27 kt	2,423 ft. airdrop
HARRY	5/19/53	4:05 a.m. PST	32 kt	300 ft. tower
GRABLE	5/25/53	7:30 a.m. PST	15 kt	524 ft. 280 mm gun
CLIMAX	6/04/53	3:15 a.m. PST	61 kt	1,334 ft. airdrop

APPENDIX "B" (Continued)

TABLE OF NTS NUCLEAR TEST SERIES AND EVENTS

Event	Date	Time	Yield	Type
		Operation TEAPOT		
WASP	2/18/55	12:00 noon PST	1 kt	762 ft. airdrop
MOTH	2/22/55	5:45 a.m. PST	2 kt	300 ft. tower
TESLA	3/01/55	5:30 a.m. PST	7 kt	300 ft. tower
TURK	3/07/55	5:20 a.m. PST	43 kt	500 ft. tower
HORNET	3/12/55	5:20 a.m. PST	4 kt	300 ft. tower
BEE	3/22/55	5:05 a.m. PST	8 kt	500 ft. tower
ESS	3/23/55	12:30 p.m. PST	1 kt	subsurface shaft
APPLE-1	3/29/55	4:55 a.m. PST	14 kt	500 ft. tower
WASP PRIME	2/29/55	10:00 a.m. PST	3 kt	739 ft. airdrop
HA	4/06/55	10:00 a.m. PST	3 kt	32,582 ft. airdrop
POST	4/09/55	4:30 a.m. PST	2 kt	300 ft. tower
MET	4/15/55	11:15 a.m. PST	22 kt	400 ft. tower
APPLE-2	5/05/55	5:10 a.m. PST	29 kt	500 ft. tower
ZUCCHINI	5/15/55	5:00 a.m. PST	28 kt	500 ft. tower
		Operation PLUMBBOB		
BOLTZMAN	5/28/57	4:55 a.m. PDT	12 kt	500 ft. tower
FRANKLIN	6/02/57	4:55 a.m. PDT	140 t	300 ft. tower
LASSEN	6/05/57	4:45 a.m. PDT	0.5 t	500 ft. balloon
WILSON	6/18/57	4:45 a.m. PDT	10 kt	500 ft. balloon
PRISCILLA	6/24/57	6:30 a.m. PDT	37 kt	700 ft. balloon
COULOMB-A	7/01/57	10:30 a.m. PDT	—	safety test
HOOD	7/05/57	4:40 a.m. PDT	74 kt	1,500 ft. balloon
DIABLO	7/15/57	4:30 a.m. PDT	17 kt	500 ft. tower
JOHN	7/19/57	7:00 a.m. PDT	2 kt	20,000 ft. rocket
KEPLER	7/24/57	4:50 a.m. PDT	10 kt	500 ft. tower
OWENS	7/25/57	6:30 a.m. PDT	9.7 kt	500 ft. balloon
PASCAL-A	7/26/57	1:00 a.m. PDT	—	underground safety experiment
STOKES	8/07/57	5:25 a.m. PDT	19 kt	1,500 ft. balloon
SATURN	8/10/57	6:00 p.m. PDT	—	(see PASCAL-A)
SHASTA	8/18/57	5:00 a.m. PDT	17 kt	500 ft. tower
DOPPLER	8/23/57	5:30 a.m. PDT	11 kt	1,500 ft. balloon
PASCAL-B	8/27/57	3:35 p.m. PDT	0.3 kt	500 ft. underground
FRANKLIN'	8/30/57	5:40 a.m. PDT	4.7 kt	750 ft. balloon
SMOKY	8/31/57	5:30 a.m. PDT	44 kt	700 ft. tower
GALILEO	9/02/57	5:40 a.m. PDT	11 kt	500 ft. tower
WHEELER	9/06/57	5:45 a.m. PDT	197 t	500 ft. balloon
COULOMB-B	9/06/57	1:05 p.m. PDT	0.3 kt	3 ft. surface
LAPLACE	9/08/57	6:00 a.m. PDT	1 kt	750 ft. balloon
FIZEAU	9/14/57	9:45 a.m. PDT	11 kt	500 ft. tower

Event	Date	Time	Yield	Type
NEWTON	9/16/57	5:50 a.m. PDT	12 kt	1,500 ft. balloon
RAINIER	9/19/57	10:00 a.m. PDT	1.7 kt	800 ft. underground*
WHITNEY	9/23/57	5:30 a.m. PDT	19 kt	500 ft. tower
CHARLESTON	9/28/57	6:00 a.m. PDT	12 kt	1,500 ft. balloon
MORGAN	10/07/57	5:00 a.m. PST	8 kt	500 ft. balloon
PASCAL-C	12/06/57	12:15 p.m. PST	—	250 ft. underground
COULOMB-C	12/09/57	12:00 noon PST	0.5 kt	surface
VENUS	2/22/58	5:00 p.m. PST	—	−100 ft. tunnel
URANUS	3/14/58	2:00 p.m. PST	—	−114 ft. tunnel
		Operation HARDTACK II		
OTERO	9/12/58	1:00 p.m. PDT	38 t	480 ft. deep well
BERNALILLO	9/17/58	12:30 p.m. PDT	15 t	456 ft. deep well
EDDY	9/19/58	7:00 a.m. PDT	83 t	500 ft. balloon
LUNA	9/21/58	12:00 noon PDT	1.5 t	484 ft. deep well
MERCURY	9/23/58	3:00 p.m. PDT	—	−183 ft. tunnel
VALENCIA	9/26/58	1:00 p.m. PDT	2 t	484 ft. deep well
MARS	9/28/58	5:00 p.m. PDT	13 t	−140 ft. tunnel
MORA	9/29/58	6:05 a.m. PST	2 kt	1,500 ft. balloon
COLFAX	10/05/58	8:15 a.m. PST	5.5 t	−350 ft. deep well
HIDALGO	10/05/58	6:10 a.m. PST	77 t	377 ft. balloon
TAMALPAIS	10/08/58	2:00 p.m. PST	72 t	−300+ ft. tunnel
QUAY	10/10/58	6:30 a.m. PST	79 t	100 ft. tower
LEA	10/13/58	5:20 a.m. PST	1.4 kt	1,500 ft. balloon
NEPTUNE	10/14/58	10:00 a.m. PST	115 t	−98.5 ft. tunnel
HAMILTON	10/15/58	8:00 a.m. PST	1.2 t	50 ft. tower
LOGAN*	10/16/58	10:00 p.m. PST	5 kt	−830 ft. tunnel
DONA ANA	10/16/58	6:20 a.m. PST	37 t	450 ft. balloon
VESTA	10/17/58	3:00 p.m. PST	24 t	surface (bldg.)
RIO ARRIBA	10/18/58	6:25 a.m. PST	90 t	72.5 ft. tower
SAN JUAN*	10/20/58	6:30 a.m. PST	—	234 ft. deep well
SOCORRO	10/22/58	5:30 a.m. PST	6 kt	1,450 ft. balloon
WRANGELL	10/22/58	8:50 a.m. PST	115 t	1,500 ft. balloon
RUSHMORE	10/22/58	3:40 p.m. PST	188 t	500 ft. balloon
OBERON	10/22/58	12:30 p.m. PST	—	25 ft. tower
CATRON	10/24/58	7:00 a.m. PST	21 t	72.5 ft. tower
JUNO	10/24/58	8:01 a.m. PST	1.7 t	surface (bldg.)
CERES	10/26/58	8:00 p.m. PST	0.7 t	25 ft. tower
SANFORD	10/26/58	2:20 a.m. PST	4.9 kt	1,500 ft. balloon
DE BACA	10/26/58	8:00 a.m. PST	2.2 kt	1,500 ft. balloon
CHAVES	10/27/58	6:30 a.m. PST	0.6 t	52.5 ft. tower
EVANS*	10/29/58	4:00 p.m. PST	55 t	−852 ft. tunnel
HUMBOLDT	10/29/58	6:45 a.m. PST	7.8 t	25 ft. tower
SANTA FE	10/29/58	7:00 p.m. PST	1.3 kt	1,500 ft. balloon
BLANCA	10/30/58	7:00 a.m. PST	19 kt	−987 ft. tunnel

APPENDIX "B" (Continued)

TABLE OF NTS NUCLEAR TEST SERIES AND EVENTS

Event	Date	Time	Yield	Type
GANYMEDE*	10/30/58	3:00 a.m. PST	0.0 t	surface (bldg)
TITANIA	10/30/58	12:34 p.m. PST	0.2 t	25 ft. tower
		Operation NOUGAT**		
ANTLER	9/15/61	9:00 a.m. PST	2.4 kt	−1,319 ft. tunnel
FEATHER	12/22/61	8:30 a.m. PST	low	−812 ft. tunnel
***				
PAMPAS	3/01/62	11:10 a.m. PST	low	1,191 ft. underground
DANNY BOY	3/05/62	10:15 a.m. PST	0.42 kt	110 ft. underground
***				
PLATTE	4/14/62	10:00 a.m. PST	1.7 kt	−560 ft. tunnel
***				
EEL	5/19/62	7:00 a.m. PST	low	714 ft. underground
***				
DES MOINES	6/13/62	1:00 p.m. PST	low	610 ft. underground
***				
SEDAN	7/06/62	9:00 a.m. PST	104 kt	635 ft. underground

from: U.S. Dept. of Energy, Announced United States Nuclear Tests July 1945 Through December 1979 (Jan. 1980), PX-728; id., July 1945 Through December 1981 (Jan. 1982), DX-1007, "Compilation of Local Fallout Data from Test Detonations 1945-1962 Extracted From DASA 1251," vol. 1, Continental U.S. Tests, H. Hawthorne, ed. (May 1979), PX-1021. See id., PX-1021, for additional information about listed tests or 1962 tests not listed.

*explosion debris contained underground or in structure. No release of radioactive material.

**Operation NOUGAT tests which did not result in release of radioactive material detected off-site have been deleted. The notation "low" yield indicates a detonation smaller than 20 kt.

—Where no yield figure is provided, actual yield was reported to be less than 0.1 ton TNT equivalence.

(THIS PAGE LEFT BLANK INTENTIONALLY)

(THIS PAGE LEFT BLANK INTENTIONALLY)

APPENDIX "C"—ORERP DOCUMENTS (DX-1118)

NUMBER OF OFFSITE MONITORS

Year	Series	Number	Affiliation	Reference Source
1951	RANGER	18	LASL	WT-204 (CIC 69)
		14	AEC Area Offices	
		8	AEC Protective Force	
		6	U.S. Army Engineer Corps	
	TOTAL	46		
1951	BUSTER/JANGLE	9	LASL (H Division)	
		52	Military	
		20	AEC Offices	WT 425 (EX)
	TOTAL	81		(CIC 8803)
1952	TUMBLER/SNAPPER	26	MILITARY	WT 558 (DEL)
				(CIC 80)
1953	UPSHOT/KNOTHOLE	2	LASL	WT-702 Ref
		10	Military	(CIC 4347)
		25	USPHS	
	TOTAL	37		
1955	TEAPOT	66	USPHS	CIC 697
		41	UCLA	
	TOTAL	107		
1957	PLUMBBOB	50	UCLA	
		148	USPHS	OTO-57-3
	TOTAL	198		(CIC 1010)
1958	HARDTACK II	25	USPHS	(CIC 6180)
				OTO-58-6
1961–62	NOUGAT	76	USPHS	SWRHL-lr
				(CIC 1012)
	GRAND TOTAL	596		

HISTORICAL DOSIMETRY DATA BASE (FILM BADGE)
TOTAL RECORDS = 15646 (thru Nougat)

SERIES	PERIOD	NO. FILMS
TUMBLER-SNAPPER	1952	36*
UPSHOT-KNOTHOLE	1953	923**
TEAPOT	1955	4167
PLUMBBOB	1957	9175
HARDTACK	1958	424
NOUGAT	1961–62	921
STORAX	1962–63	2,580
DOMINIC II	1962	2,580
NIBLIC through TOGGLE	1963–72	2,700 per year

*DOD REPORT
**DOSIMETRY RESEARCH PROJECT DATA BASE + WT-817

SURVEY METER RECORDS

YEAR	SERIES	NUMBER OF RECORDS
1951	RANGER	*
1951	BUSTER/JANGLE	*
1952	TUMBLER/SNAPPER	2,257
1953	UPSHOT/KNOTHOLE	5,644
1955	TEAPOT	7,138
1957	PLUMBBOB	30,156
1958	HARDTACK II	1,348
1961–62	NOUGAT	2,189
1962–63	STORAX	2,518

*LOCATION UNKNOWN AT THIS TIME.

NUMBER OF ENVIRONMENTAL SAMPLES ANALYZED

YEAR	AIR SAMPLES	WATER SAMPLES	MILK SAMPLES
1953	5610		
1955	5940	179	155
1957	4440	253	198
1958	4650*	47	140
1959	3630	12	165
1969	3630	87	550
1961	3830	172	1770
1962	6950	351	6500
1963	8910	527	3810
1964	14520	482	4227
1965	32600	614	5200
1966	31800	1064	4361
1967	31800	1095	4345

*11 SAMPLES CHECKED FOR IODINE. HIGHEST WAS 85 pCi/LITER—OVERTON AND ST. GEORGE.

FALLOUT COLLECTORS ANALYZED FOR NUCLEAR DEBRIS*

	TRAYS (WITH RESULTS)	GRANULAR COLLECTORS	GUMMED FILM	RESIN PLATES	TUB LINER
BUSTER/JANGLE	54 (WT-425(EX))				12 (CIC-6626)
TUMBLER/SNAPPER	113 (WT-558)				
UPSHOT/KNOTHOLE	346 (LASL LOGS)				
TEAPOT			188 (WT-1178)		
PLUMBBOB	70 (HOOD ONLY) (CIC-220)	2680 (WT-1488)		240 (WT-1488)	

*CURRENT ESTIMATED NUMBER OF COLLECTORS WITHIN 200 MILES OF THE TEST SITE.

(THIS PAGE LEFT BLANK INTENTIONALLY)

APPENDIX "D"

MELTING AND BOILING POINTS, AND ATOMIC WEIGHTS OF THE ELEMENTS

Based on the Assigned Relative Atomic Mass of $^{12}C = 12$

The following values apply to elements as they exist in materials of terrestrial origin and to certain artificial elements. When used with the footnotes, they are reliable to ±3 if that digit is in small type.

Name	Symbol	Atomic number	Atomic weight	Melting point, °C	Boiling point, °C
Actinium[a]	Ac	89	227.028	1,050	3,200 ± 300
Aluminum	Al	13	26.98154[b]	660.37	2,467
Americium	Am	95	(243)	994 ± 4	2,607
Antimony	Sb	51	121.75[e]	630.74	1,750
Argon[b,j]	Ar	18	39.948[e,b,c,d,g]	−189.2	−185.7
Arsenic (gray)	As	33	74.9216[e]	817 (28 atm)	613 (sub.)
Astatine	At	85	(210)	302	337
Barium[i]	Ba	56	137.33	725	1,640
Berkelium	Bk	97	(247)	—	—
Beryllium	Be	4	9.01218[e]	1,278 ± 5	2,970 (5 mm)
Bismuth	Bi	83	208.9804[e]	271.3	1,560 ± 5
Boron[b,j]	B	5	10.81[c,d,e]	2,300	2,550 (sub.)
Bromine	Br	35	79.904[c]	−7.2	58.78
Cadmium[i]	Cd	48	112.41	320.9	765
Calcium[i]	Ca	20	40.08	839 ± 2	1,484

APPENDIX "D" (Continued)

MELTING AND BOILING POINTS, AND ATOMIC WEIGHTS OF THE ELEMENTS

Name	Symbol	Atomic number	Atomic weight	Melting point, °C	Boiling point, °C
Californium	Cf	98	(251)	—	—
Carbon[b,l]	C	6	12.011[b,d]	3,652 (sub)	
Cerium[l]	Ce	58	140.12	798 ± 3	3,257
Cesium	Cs	55	132.9054[c]	28.40 ± 0.01	669.3
Chlorine	Cl	17	35.453[c]	−100.98	−34.6
Chromium	Cr	24	51.966[c]	1,857 ± 20	2,672
Cobalt	Co	27	58.9332[a]	1,495	2,870
Copper[b]	Cu	29	63.546*[c,d]	1,083.4 ± 0.2	2,567
Curium	Cm	96	(247)	1,340 ± 40	
Dysprosium	Dy	66	162.50*	1,409	2,335
Einsteinium	Es	99	(254)	—	—
Erbium	Er	68	167.26*	1,522	2,510
Europium[l]	Eu	63	151.96	822 ± 5	1,597
Fermium	Fm	100	(257)	—	—
Fluorine	F	9	18.998403[a]	−219.62	−188.14
Francium	Fr	87	(223)	(27)	(677)
Gadolinium[l]	Gd	64	157.25*	1,311 ± 1	3,233
Gallium	Ga	31	69.72	29.78	2,403
Germanium	Ge	32	72.59*	937.4	2,830
Gold	Au	79	196.9665[a]	1,064.43	3,080
Hafnium	Hf	72	178.49*	2,227 ± 20	4,602
Helium[l]	He	2	4.00260[b]	−272.2[26 atm]	−268.934

MELTING AND BOILING POINTS, AND ATOMIC WEIGHTS OF THE ELEMENTS

Name	Symbol	Atomic number	Atomic weight	Melting point, °C	Boiling point, °C
Holmium	Ho	67	164.9304[a]	1,470	2,720
Hydrogen[b]	H	1	1.0079[b,d]	−259.14	−252.87
Indium[f]	In	49	114.82	156.61	2,080
Iodine	I	53	126.9045[a]	113.5	184.35
Iridium	Ir	77	192.22*	2,410	4,130
Iron	Fe	26	55.847*	1,535	2,750
Krypton[i,j]	Kr	36	83.80	−156.6	−152.30 ± 0.10
Lanthanum[f]	La	57	138.9055*[b]	920 ± 5	3,454
Lawrencium	Lr	103	(260)	—	—
Lead[b,j]	Pb	82	207.2[d,g]	327.502	1,740
Lithium[b,i,j]	Li	3	6.941*[c,d,e]	180.54	1,342
Lutetium	Lu	71	174.967 ± 0.003	1,656 ± 5	3,315
Magnesium[f]	Mg	12	24.305[c]	648.8 ± 0.5	1,090
Manganese	Mn	25	54.9380[a]	1,244 ± 3	1,962
Mendelevium	Md	101	(257)	—	—
Mercury	Hg	80	200.59*	−38.87	356.58
Molybdenum	Mo	42	95.94	2,617	4,612
Neodymium[f]	Nd	60	144.24*	1,010	3,127
Neon[j]	Ne	10	20.179*[c]	−248.67	−246.048
Neptunium[k]	Np	93	237.0482[b]	640 ± 1	3,902
Nickel	Ni	28	58.70	1,453	2,732

APPENDIX "D" (Continued)

MELTING AND BOILING POINTS, AND ATOMIC WEIGHTS OF THE ELEMENTS

Name	Symbol	Atomic number	Atomic weight	Melting point, °C	Boiling point, °C
Niobium (Columbium)	Nb	41	92.9064[a]	2,468 ± 10	4,742
Nitrogen	N	7	14.0067[b,c]	−209.86	−195.8
Nobelium	No	102	(259)	—	—
Osmium[f]	Os	76	190.2	3,045 ± 30	5,027 ± 100
Oxygen[h]	O	8	15.9994*[b,c,d]	−218.4	−182.962
Palladium[f]	Pd	46	106.4	1,554	3,140
Phosphorus	P	15	30.97376	44.1 (white)	280 (white)
Platinum	Pt	78	195.09*	1,772	3,827 ± 100
Plutonium	Pu	94	(244)	641	3,232
Polonium	Po	84	(209)	254	962
Potassium	K	19	39.0983*	63.25	759.9
Praesodymium	Pr	59	140.9077[a]	931 ± 4	3,212
Promethium	Pm	61	(145)	~1,080	2,460(?)
Protactinium[h]	Pa	91	231.0359[a]	<1,600	—
Radium[f,h]	Ra	88	226.0254[a,f,g]	700	1,140
Radon	Rn	86	(222)	−71	−61.8
Rhenium	Re	75	186.2	3,180	5,627 (est.)
Rhodium	Rh	45	102.9055[a]	1,966 ± 3	3,727 ± 100
Rubidium[f]	Rb	37	85.4678*[e]	38.89	686
Ruthenium[f]	Ru	44	101.07*	2,310	3,900
Samarium[f]	Sm	62	150.4	1,072 ± 5	1,778

MELTING AND BOILING POINTS, AND ATOMIC WEIGHTS OF THE ELEMENTS

Name	Symbol	Atomic number	Atomic weight	Melting point, °C	Boiling point, °C
Scandium	Sc	21	44.9559[a]	1,539	2,832
Selenium	Se	34	78.96*	217	684.9 ± 1.0
Silicon	Si	14	28.0855*	1,410	2,355
Silver[i]	Ag	47	107.868[c]	961.93	2,212
Sodium	Na	11	22.98977[a]	97.81 ± 0.03	882.9
Strontium[i]	Sr	38	87.62[g]	769	1,384
Sulfur[h]	S	16	32.06[d]	112.8	444.674
Tantalum	Ta	73	180.9479*[b]	2,996	5,425 ± 100
Technetium	Tc	43	(97)[f]	2,172	4,877
Tellurium[i]	Te	52	127.60*	449.5 ± 0.3	989.8 ± 3.8
Terbium	Tb	65	158.9254[a]	1,360 ± 4	3,041
Thallium	Tl	81	204.37*	303.5	1,457 ± 10
Thorium[j,k]	Th	90	232.0381[a]	1,750	~4,790
Thulium	Tm	69	168.9342[a]	1,545 ± 15	1,727
Tin	Sn	50	118.69*	231.9681	2,270
Titanium	Ti	22	47.90*	1,660 ± 10	3,287
Tungsten	W	74	183.85*	3,410 ± 20	5,660
Uranium[i,j]	U	92	238.029[b,c,e]	1,132.3 ± 0.8	3,818
Vanadium	V	23	50.9415*[b,c]	1,890 ± 10	3,380
Wolfram (see Tungsten)					

APPENDIX "D" (Continued)

MELTING AND BOILING POINTS, AND ATOMIC WEIGHTS OF THE ELEMENTS

Name	Symbol	Atomic number	Atomic weight	Melting point, °C	Boiling point, °C
Xenon[a,j]	Xe	54	131.30	−111.9	−107.1 ± 3
Ytterbium	Yb	70	173.04[e]	824 ± 5	1,193
Yttrium	Y	39	88.9059[a]	1,523 ± 8	3,337
Zinc	Zn	30	65.38	419.58	907
Zirconium[i]	Zr	40	91.22	1,852 ± 2	4,377

[a]Mononuclidic element.
[b]Element with one predominant isotope (about 99 to 100% abundance).
[c]Element for which the atomic weight is based on calibrated measurements.
[d]Element for which variation in isotropic abundance in terrestrial samples limits the precision of the atomic weight given.
[e]Element for which users are cautioned against the possibility of large variations in atomic weight due to inadvertent or undisclosed artificial isotropic separation in commercially available materials.
[f]Most commonly available long-lived isotope.
[g]In some geological specimens this element has a highly anomalous isotopic composition, corresponding to an atomic weight significantly different from that given.
[h]Element for which known variations in isotopic composition in normal terrestrial material prevent a more precise atomic weight given; A_r (E) values should be applicable to any "normal" material.
[i]Element for which geological specimens are known in which the element has an anomalous isotopic composition, such that the difference in atomic weight of the element in such specimens from that given in the Table may exceed considerably the implied uncertainty.

[j]Element for which substantial variations in A_r from the value given can occur in commercially available material because of inadvertent or undisclosed change of isotopic composition.

[k]Element for which the value A_r is that of the radioisotope of longest half-life.

[l]Triple point: (graphite-liquid gas), 3627 ± 50°C at a pressure of 10.1 MPa and (graphite-diamond-liquid), 3830 – 3930°C at a pressure of 12 – 13 GPa.

From: Handbook of Chemistry and Physics (64th ed. Weast 1983)

(THIS PAGE LEFT BLANK INTENTIONALLY)

APPENDIX C

Opinion of the Federal District Court

District of Utah, filed August 21, 1981

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF UTAH

CENTRAL DIVISION

IRENE H. ALLEN, et al.,	)	Civil No. C 79-0515
	)	
Plaintiffs,	)	
	)	
vs.	)	MEMORANDUM
	)	OPINION
UNITED STATES OF AMERICA,	)	and ORDER
	)	
Defendant.	)	

The above-entitled action was brought by nearly 1,000 persons against the United States government for injuries alleged to have been individually sustained as a result of the government's program of open-air testing of nuclear weapons at its Nevada Test Site conducted from 1951 through 1962. The plaintiffs, residents of Utah, Nevada and Arizona, assert broad allegations of negligence on the part of federal agencies and personnel in the conduct of the testing program, including breach by the government of an alleged continuing duty to conduct the tests in a manner that was reasonably safe to life and property, to warn persons in affected communities, including the plaintiffs, of the risks and potential consequences of exposure to radioactive fallout generated by the tests, and to take adequate precautions to minimize or eliminate exposure of civilians to harmful fallout radiation. This action was filed in this Court pursuant to the Federal Tort Claims Act, 28 U.S.C. §§ 1346(b), 2671 et seq.

On April 27, 1981, the defendant filed two motions to dismiss the complaint for want of subject-matter jurisdiction. See Rule 12(b) (1), Federal Rules of Civil Procedure. The first motion asserts that this

Court lacks jurisdiction of the plaintiffs' claims on the ground that they all allege injuries resulting from governmental conduct that comes within the scope of 28 U.S.C. § 2680(a), the discretionary function exception to the Federal Tort Claims Act.[1] The second motion asserts that the plaintiffs' claims "accrued" more than two years before any action was taken pursuant to the Federal Tort Claims Act and are therefore barred by the applicable statute of limitations, 28 U.S.C. § 2401(b).[2]

The parties filed extensive memoranda, including voluminous attachments and exhibits.[3] On June 4, 1981, the motions to dismiss came on for hearing before this Court. This Court, having heard and considered the arguments of learned counsel on both sides, having reviewed the documentation and memoranda submitted by the parties, and having given attention to the applicable legal authorities, now rules on the defendant's motions to dismiss as follows:

---

[1] 28 U.S.C. § 2680(a) provides:

The provisions of this chapter and section 1346(b) of this title shall not apply to—

(a) Any claim based upon an act or omission of an employee of the Government, exercising due care, in the execution of a statute or regulation, whether or not such statute or regulation be valid, or based upon the exercise or performance or the failure to exercise or perform a discretionary function or duty on the part of a federal agency or an employee of the Government, whether or not the discretion involved be abused. (Emphasis added.)

[2] 28 U.S.C. § 2401(b) provides:

(b) A tort claim against the United States shall be forever barred unless it is presented in writing to the appropriate Federal agency within two years after such claim accrues or unless action is begun within six months after the date of mailing, by certified or registered mail, of notice of final denial of the claim by the agency to which it was presented.

[3] The memoranda and attachments submitted to this Court amount to a 12-inch pile of documents, not including more than 3,900 pages of congressional committee hearings reproduced in three volumes. A number of the documents so submitted are honey-combed by blank spaces stamped "deleted." The exhibits also include a videotape presentation of a government documentary on nuclear testing. The text of the film's narration was transcribed and included in the transcript of the hearing on the motions.

I. THE DISCRETIONARY FUNCTION EXCEPTION

The discretionary function exception to the Federal Tort Claims Act, 28 U.S.C. § 2680(a), has been the subject of extensive litigation and of professional and scholarly comment. See e.g., Reynolds, "The Discretionary Function Exception of the Federal Tort Claims Act," 57 Georgetown Law Journal 81 (1968); Annot., 37 A.L.R. Fed 537 (1978); Annot., 36 A.L.R. Fed 240 (1978); Annot., 35 A.L.R. Fed 481 (1977); Annot., 99 A.L.R. 2d 1016 (1965). Of the exceptions to the Government's waiver of sovereign immunity under the Federal Tort Claims Act, the discretionary function exception has by far the greatest potential for repeated and varied application. The other exceptions bar litigation by certain classes of plaintiffs or the adjudication of specific categories of claims. The discretionary function exception compels an examination of the intrinsic nature of the Government's conduct, no matter who the plaintiff is or what interest the plaintiff asserts has been injured by that conduct.

Read broadly, the discretionary function exception may easily swallow the rule; the stopping of a government truck at a highway stop sign involves choice, judgment, assessment of risks—discretion in the broadest sense.[3A] Clearly the courts must sort the intrinsically discretionary from the truly operational if the Federal Tort Claims Act is to have any meaningful application at all.

The initial outline of the reach of the exception was traced by the United States Supreme Court in Dalehite v. United States, 346 U.S. 15 (1953), involving claims arising from the cataclysmic explosion of shiploads of government fertilizer at Texas City, Texas. In Dalehite, the Supreme Court held the plaintiffs' claims against the United States for negligent planning and handling of the fertilizer shipment to be encompassed within the discretionary function exception. Justice Reed couched this finding in broad terms:

[3A] But see Dalehite v. United States, 346 U.S. 15, 34 (1953) ("[W]e know that the draftsmen did not intend it to relieve the Government from liability for such common law torts as an automobile collision caused by the negligence of an employee . . . of the administering agency.")

> It is unnecessary to define, apart from this case, precisely where discretion ends. It is enough to hold, as we do, that the "discretionary function or duty" that cannot form a basis for suit under the Tort Claims Act includes more than the initiation of programs and activities. It also includes determinations made by executives or administrators in establishing plans, specifications or schedules of operations. Where there is room for policy judgment and decision there is discretion.

Id., 346 U.S. at 35-36 (emphasis added).

Since Dalehite the federal courts have struggled repeatedly to formulate a principled analysis of governmental conduct that will effectively guide the application of the discretionary function exception, see, e.g., Blessing v. United States, 447 F.Supp. 1160 (E.D.Pa. 1978), and cases cited therein; Jackson v. Kelly, 557 F.2d 735, 737 (10th Cir. 1977), while remaining consistent with the broad language of Dalehite. See Barton v. United States, 609 F.2d 977, 979 (10th Cir. 1979) ("The basic authority is Dalehite v. United States, . . ."). No "precise litmus paper test," Payton v. United States, 636 F.2d 132, 143 (5th Cir. 1981), has yet emerged. See, e.g., Baird v. United States, _____ F.2d _____, _____, No. 79-1441 (10th Cir., dec. June 29, 1981), slip op. at 13-14.

Instead, the courts have looked to the policies underlying the discretionary function exception and have balanced those against the policies served by the Federal Tort Claims Act. As the United States Court of Appeals for the Fifth Circuit pointed out in Payton v. United States, 636 F.2d 132 (5th Cir. 1981), "The crux of the concept embodied in the discretionary function exception is that of separation of powers." Id. at 143 (footnote omitted). Judge Becker in Blessing v. United States, 447 F.Supp. 1160, 1170 (E.D.Pa. 1978) skillfully elaborates on this notion:

> Read as a whole and with an eye to descerning a policy behind this provision, it seems to us only to articulate a policy of preventing tort actions from becoming a vehicle for judicial interference with decisionmaking that is properly exercised by other branches of the government and of protecting "the

> Government from liability that would seriously handicap efficient government operations," United States v. Muniz, 374 U.S. 150, 163 . . . Statutes, regulations, and discretionary functions, the subject matter of § 2680(a), are, as a rule, manifestations of policy judgments made by the political branches. In our tripartite governmental structure, the courts generally have no substantive part to play in such decisions. Rather the judiciary confines itself . . . to adjudication of facts based upon discernible objective standards of law. In the context of tort actions, . . . these objective standards are notably lacking when the question is not negligence but social wisdom, not due care but political practicability, not reasonableness but economic expediency. Tort law simply furnishes an inadequate crucible for testing the merits of social, political, or economic decisions.

Id., 447 F.Supp. at 1170 (footnotes omitted and emphasis added).[4]

This concern for the non-justiciability of questions of political, social or economic policy, a concern long-recognized under traditional separation of powers principles, finds some reflection in the legislative history of the discretionary function exception, see e.g., Hearings on H.R. 5373 and 6463, House Committee on the Judiciary, 77th Cong., 2d Sess., at 29 (1942) (Statement of Francis M. Shea), and in the Supreme Court's initial construction of the exception in Dalehite v. United States, supra, 346 U.S. at 34 ("The 'discretion' protected by the section . . . is the discretion of the executive or administrator to act according to one's judgment of the best course, a concept of substantial historical ancestry in American law." [footnote omitted]). In Dalehite, Justice Reed attempted to define the limits of protected discretion through reference to the "planning" level as opposed to the "operational" level of government activity; conduct at the planning level is discretionary and therefore immune, conduct at the operational level is not. Dalehite, however, gives little transferable guidance in determining where "planning" stops and "operations" begin. Some light was shed upon the subject by the Supreme Court in its subsequent decision in Indian Towing Co. v. United States, 350 U.S. 61 (1955), involving alleged negligence by the Coast Guard in

[4] But see L. Green, "Tort Law Public Law in Disguise" 38 Texas L.Rev. 1 (1959).

the operation of a coastal lighthouse. In Indian Towing, Justice Frankfurter's opinion for the majority distinguished Dalehite and held the Government liable for its alleged negligence:

> The Coast Guard need not undertake the lighthouse service. But once it exercised its discretion to operate a light on Chandeleur Island and engendered reliance on the guidance afforded by the light, it was obligated to use due care to make certain that the light was kept in good working order; and, if the light did become extinguished, then the Coast Guard was further obligated to use due care to discover this fact and to repair the light or give warning that it was not functioning. If the Coast Guard failed in its duty and damage was thereby caused to petitioners, the United States is liable under the Tort Claims Act.
>
> * * * *
>
> The differences between this case and Dalehite need not be labored. The governing factors in Dalehite sufficiently emerge from the opinion in that case.

Id., 350 U.S. at 69 (footnote omitted).

Certainly the details of lighthouse operation involved questions requiring levels of choice, judgment—discretion in the broad sense.

In Rayonier, Inc. v. United States, 352 U.S. 319 (1957) again the Supreme Court considered Government liability for actions involving some degree of independent judgment and held the Government to be liable without even discussing the discretionary function exception. In Rayonier, the plaintiffs were damaged as a result of a fire that raged out of control because of the alleged negligence in the firefighting strategy and tactics of federal officials. The allegations included allegations of negligence in the "planning" stages of the federal fire control effort. Rejecting language from Dalehite that found no private cause of action for governmental negligence in fire-fighting, the Court construed the Federal Tort Claims Act's waiver of sovereign immunity to encompass the plaintiff's claims. The decisions of the federal officials in Rayonier seem at face value no less discretionary than some of those immunized in Dalehite: exercising judgment in

withdrawing firemen from a location seems no more "ministerial" or "operational" than exercising judgment in deciding to fill paper bags with ammonium nitrate fertilizer at a given temperature and humidity.

Some lower federal courts, while treating the Dalehite case as the leading opinion on the scope of 28 U.S.C. § 2680(a), have cautiously observed the apparent narrowing of Dalehite by Indian Towing and Rayonier. See Relf v. United States, 433 F.Supp. 423, 427 D.D.C. 1977). The "planning/operational" distinction offered by Justice Reed in Dalehite has grown increasingly ineffective in harmonizing the results of subsequent cases. See Hatahley v. United States, 351 U.S. 173 (1956); United States v. Muniz, 374 U.S. 150 (1963); compare, e.g., Ashley v. United States, 215 F.Supp. 39, 45-46 (D.Neb. 1963) (field decision on how to handle a troublesome bear in a National Park held "discretionary"), affirmed, 326 F.2d 499 (8th Cir. 1964), with Downs v. United States, 522 F.2d 990 (6th Cir. 1975) (FBI agent's decision on how to handle an airplane hijacking not "discretionary").

In Smith v. United States, 375 F.2d 243 (5th Cir. 1967), the Fifth Circuit discarded the "planning/operational" distinction in favor of an approach looking to the policies underpinning the discretionary function exception and to the nature of the discretion involved in each case:

> If the Tort Claims Act is to have the corpuscular vitality to cover anything more than automobile accidents in which government officials were driving, the federal courts must reject an absolutist interpretation of Dalehite, and that interpretation is rejected by Indian Towing and especially by Rayonier. . . . Cases under the Act therefore put courts to the question of what sorts of decisions can be classified as resulting from discretion within the meaning of § 2680(a). It is not a sufficient defense for the government merely to point out that some decision-making power was exercised by the official whose act was questioned. Answering these questions, a difficult process, is not aided by importation of the planning stage—operational stage standard as argued for . . . Such a distinction is specious.

> It may be a makeweight in easy cases where of course it is not needed, but in difficult cases it proves to be another example of a distinction "so finespun and capricious as to be almost incapable of being held in mind for adequate formulation." Mr. Justice Frankfurter for the Court in Indian Towing, supra, 350 U.S. at 68 . . . Such nonstatutory "aids" to construction tend to obscure, to limit, or even to replace the standards whose meaning they are supposed to clarify. . . . It must be remembered that the question at hand here is the nature and quality of the discretion involved in the acts complained of.

Id., 375 F.2d at 246 (emphasis added, footnote and citations omitted). In Smith, the plaintiff sought damages for the failure of the Government to prosecute persons allegedly injuring his business through boycotts and picketing. Recalling that court's earlier conclusion in United States v. Cox, 342 F.2d 167, 171 (5th Cir. 1965) that "as an incident of the constitutional separation of powers, . . . the courts are not to interfere with the free exercise of the discretionary powers of the attorneys of the United States in their control over criminal prosecutions," Judge Goldberg held 28 U.S.C. § 2680(a) to apply:

> We therefore hold that § 2680(a) exempts the government from liability for exercising the discretion inherent in the prosecutorial function of the Attorney General, no matter whether these decisions are made during the investigation or prosecution of offenses. See United States v. Faneca, 5 Cir. 1964, 332 F.2d 872. Another holding could diffuse the government's control over policies committed to it by the Constitution, and irrationally concentrate political responsibility in fortuitous lawsuits.
>
> Whatever else § 2680(a) may do, its discretionary function exception prevents this diffusion of governmental power into private hands. The United States is immune from liability in the present case not because of the mere fact that government officials made choices, but because the choices made affected the political (not merely the monetary) interests of the nation. The Act is intended to spread monetary losses in certain cases among the taxpayers; it is not intended to affect the distribution of political responsibility.

Id., 375 F.2d at 248 (emphasis added).

In Smith, Judge Goldberg outlines the construction of § 2680(a) in light of its fundamental purpose, preservation of the traditional constitutional separation of powers.[5] This form of analysis of the discretionary function exception has been propounded in useful detail by another fifth Circuit panel in Payton v. United States, 636 F.2d 132 (5th Cir. 1981). The Payton analysis seeks a pragmatic balancing of private and governmental interests "without the conclusory application of labels." Id., 636 F.2d 143-144.

> Considering initially the injured party, the court should review the nature of the loss imposed by the governmental injury. The more serious, in terms of physical or mental impairment, and isolated the loss the closer the question becomes as to whether the individual can be expected to absorb the loss as incident to an acceptable social or political risk of governmental activities. Other factors to be weighed are the expectation of the public or the injured party and the nature of the reliance, whether based upon a consistent level of governmental activity or upon the party's lack of foresight. However deep analysis of these considerations would be more significant in the negligence phase of the court's determinations. A further point of consideration might be the existence of alternative remedies or compensations for the injured party, since the dearth of such alternatives was a primary reason for the enactment of the [Federal Tort Claims Act].

Id., 636 F.2d at 144 (footnotes omitted). The interests of the injured party are of particular concern, according to Payton, because "the spread of monetary losses among the taxpayers is the principle concern" of the Federal Tort Claims Act. Id. Payton approaches the countervailing interests of the Government as follows:

> Looking to the government's interest, the trial court would need to assess the nature and quality of the governmental

---

[5] See Note, "Separation of Powers and the Discretionary Function Exception: Political Question in Tort Litigation Against the Government," 56 Iowa L.Rev. 930, 946 (1971).

> activity causing the injury. Smith v. United States, 375 F.2d 243, 246 (5th Cir. 1967). This could be done by examining the agency's guidelines, or procedures in the area, see, e.g., Griffin v. United States, 500 F.2d 1059, 1064-68 (3d Cir. 1974), and determining the administrative level at which the injurious activity took place. See, e.g., Hendry v. United States, 418 F.2d 774, 783 (2d Cir. 1969). Along these lines, the court must determine if the allegations attack the rules formulated by the agency or merely their application. Dalehite v. United States, 346 U.S. at 27, 35 . . . ; Hendry v. United States, 418 F.2d at 782.

Id. Drawing an analogy to Baker v. Carr, 369 U.S. 186, 217 (1962), Payton additionally inquires "whether the activity is one traditionally or constitutionally exercised by a coordinate branch of government or one fraught with political or policy overtones such as the feasibility or practicality of a program, Dalehite v. United States, 346 U.S. at 34, . . . , or prosecutorial discretion, Smith v. United States, 375 F.2d at 248, and whether this injurious activity is in an area of potential government embarrassment such as foreign affairs." Id., at 144-145 (footnote omitted). Further, Payton urges "a careful assessment of the actual burden, in both the long and short run, on governmental activities and the alternatives available . . ." Id., at 145 (footnote omitted).

Finally, Payton looks to the amenability of the subject-matter of the suit to the judicial process:

> The Court should consider, whether the vehicle of a tort suit provides the relevant standard of care, be it professional or reasonableness, for the evaluation of the governmental decision. Hendry v. United States, 418 F.2d at 783. Similarly, the Court should determine whether the factors for decision are primarily of such political, social or economic nature as to be beyond the Court's experience gained even in civil rights and antitrust litigation. . . . On this point complexity alone is not dispositive, but rather the Court should assess the nature of the complications and their amenability to the judicial process of evidential

> offering, evaluation and determination. See Griffin v. United States, 500 F.2d at 1064.

Id., at 145 (citation omitted).

In Payton, the plaintiffs alleged that the United States Board of Parole and the Bureau of Prisons negligently released on parole a dangerous convict who subsequently committed additional murders against the plaintiffs' decedents, resulting in the claim for damages for wrongful death. While the decision to release the prisoner in question certainly involved the exercise of discretion in the classic sense, the Court, led by Judge Fay, denied immunity under § 2680(a). While the Court would extend the discretionary function exception to insulate the Parole Board's formulation of its basic policies and parole guidelines, it extended immunity no farther:

> The choices involved in applying the guidelines and releasing a particular person are of another sort. Whether characterized as "operational", "day-to-day" or by some other label, they do not achieve the status of a basic policy evaluation and decision. Such decisions, if negligent, are not protected by section 2680(a).

Id., at 147.

The Fifth Circuit's limitation of the discretionary function exception to the protection of basic social, political and economic policy decisions under traditional separation of powers principles has found reflection in the analysis applied by other courts.

The United States Court of Appeals for the Third Circuit in Griffin v. United States, 500 F.2d 1059 (3d Cir. 1974), in determining the Government's liability for an administrative decision releasing a batch of live polio virus vaccine which turned out to be hazardous and resulted in injury to the plaintiffs, looked to the public policy content of the decision complained of. Rejecting the Government's broad assertion of discretionary function immunity, Judge Rosenn explained the Court's analysis of the issue, commencing with Dalehite:

> The decisions held discretionary in Dalehite involved, at minimum, some consideration as to the feasibility or practicability of Government programs. . . . Such decisions involved considerations of public policy, calling for a balance of such factors as cost of Government programs against potential benefit. . . . Where decisions have not involved policy judgments as to the public interest, the courts have not held the decisions to be immune from judicial review. . . . To determine the applicability of the discretionary function exception, therefore, we must analyze not merely whether judgment was exercised but also whether the nature of the judgment called for policy considerations.

Id., 500 F.2d at 1064 (emphasis added and citations omitted). Under Griffin, an administrative decision, though couched in the complex considerations of scientific, professional or highly technical judgment, is not "discretionary" within the meaning of 28 U.S.C. § 2680(a) unless it additionally embodies political, social or economic policy judgments traditionally insulated from judicial scrutiny by the separation of powers doctrine.

> Judicial intervention in such decision-making through the vehicle of private tort suits would involve the courts in political, economic, and social decisions in apparent violation of the separation of powers principle that we perceive the discretionary function exception statutorily to embody. Further, precisely because these decisions would require consideration of factors that are primarily political, social, and economic in nature, they, unlike the professional evaluative judgments challenged in Griffin, would not be the type of determinations that the courts are "fully capable of scrutinizing . . . by the usual standards applied to cases of professional negligence." 500 F.2d at 1066-67. . . .

Blessing v. United States, 447 F.Supp. 1160, 1180-1183 (E.D. Pa. 1978) (footnotes omitted).

Most important to the litigation now proceeding before this Court is the fact that the United States Court of Appeals for the Tenth

Circuit has expressly approved of the analytical approach applied in Griffin and similar cases. First National Bank in Albuquerque v. United States, 552 F.2d 370, 375 (10th Cir. 1977). In Jackson v. Kelley, 557 F.2d 735 (10th Cir. 1977), the Court through Chief Judge Lewis wrote:

> Generally speaking, a duty is discretionary if it involves judgment, planning, or policy decisions. It is not discretionary if it involves enforcement or administration of a mandatory duty at the operational level, even if professional expert evaluation is required. . . . The key is whether the duty is mandatory or whether the act complained of involved policy-making or judgment. . . .

Id., 557 F.2d at 737-738 (citations omitted). The Court of Appeals in Wright v. United States, 568 F.2d 153 (10th Cir. 1977) reaffirmed the "policy" approach to § 2680(a), commenting that "The 'discretionary function' exemption to tort liability is auxiliary to the government's ability to formulate and implement policy." Id., 568 F.2d at 158. See also Smith v. United States, 546 F.2d 872 (10th Cir. 1976).[6] Most recently, the Tenth Circuit Court of Appeals held the Government to be immune from liability for damages resulting from an alleged lack of important detail in an aeronautical chart produced in compliance with federal regulations, which plaintiffs claimed resulted in the crash of their aircraft. The Court found the promulgation of the governing regulations to be sufficiently imbued with pub-

---

[6] An apparent exception to the "policy" approach is the standard applied by the Tenth Circuit in Barton v. United States, 609 F.2d 977 (10th Cir. 1979). In Barton, Judge Pickett states the governing standard as follows:

> Concisely stated, the rule is that if a government official in performing his statutory duties must act without reliance upon a fixed or readily ascertainable standard, the decision he makes is discretionary and within the exception of the Tort Claims Act. Conversely, if there is a standard by which his action is measured, it is not within the exception.

Id., 609 F.2d at 979. The regulation of grazing upon the public lands at issue in Barton required the officers involved to make judgments based upon both technical and public policy considerations. In this way Barton is in fact consistent with Griffin, et al., at least in its outcome.

139 (1879), reflect a commonplace legislative judgment that a party should be put on notice to defend the legal claims against him within a reasonable time after the claims have accrued.

> These enactments are statutes of repose; and although affording plaintiffs what the legislature deems a reasonable time to present their claims, they protect defendants and the courts from having to deal with cases in which the search for truth may be seriously impaired by the loss of evidence, whether by death or disappearance of witnesses, fading memories, disappearance of documents, or otherwise. United States v. Marion, 404 U.S. 307, 322, n. 14 (1971); Burnett v. New York Central R. Co., 380 U.S. 424, 428 (1965); Chase Securities Corp. v. Donaldson, 325 U.S. 304, 314 (1945); Missouri, K. & T. R. Co. v. Harriman, 227 U.S. 657, 672 (1913); Bell v. Morrison, [26 U.S.] 1 Pet. 351, 360 (1828).

United States v. Kubrick, 444 U.S. 111, 117 (1979). 28 U.S.C. § 2401(b), the statute of limitations for the Federal Tort Claims Act, reflects the judgment of Congress that tort claims against the Government are appropriately timely if presented within two years after they accrue. Under some circumstances, however, courts have been justified in determining that a particular plaintiff's cause of action has "accrued" at a time long after the allegedly tortious conduct on the part of the defendant and long after the two-year period would normally have run. Often these are cases in which the injury to the plaintiff first manifests itself months or years following its apparent cause. See e.g., Urie v. Thompson, 337 U.S. 163 (1949); Casias v. United States, 532 F.2d 1339 (10th Cir. 1976). In such cases, the plaintiff's "blameless ignorance" of the basis for his claim is held to toll the running of the statute of limitations, notwithstanding the force of the policies favoring the statute's application. Urie v. Thompson, supra, at 169-170.

In United States v. Kubrick, 444 U.S. 111 (1979), the United States Supreme Court held that a cause of action under the Federal Tort Claims Act "accrues" when the plaintiff knows of the fact of his injury and its cause:

> That he has been injured in fact may be unknown or unknowable until the injury manifests itself; and the facts about causa-

> tion may be in the control of the putative defendant, unavailable to the plaintiff or at least very difficult to obtain. The prospect is not so bleak for a plaintiff in possession of the critical facts that he has been hurt and who has inflicted the injury. He is no longer at the mercy of the latter. There are others who can tell him if he has been wronged, and he need only ask.

Id., 444 U.S. at 122. See Nielson v. Seaborg, 348 F.Supp. 1369, 1371 (D.Utah 1972) (J. Anderson).

Kubrick does not toll the operation of the statute of limitations until a plaintiff discovers that he has a legal claim against the Government arising from his injury; a plaintiff, "armed with the facts about the harm done to him, can protect himself by seeking advice in the medical and legal community. To excuse him from promptly doing so by postponing the accrual of his claim would undermine the purpose of the limitations statute, which is to require the reasonably diligent presentation of tort claims against the Government." Id., 444 U.S. at 123 (footnote omitted). The inquiry to be made in each case, therefore, is whether the plaintiff knew (1) that he or she has been injured in fact, and (2) that he or she was injured by a particular known cause. The plaintiff need not know the full extent of his or her injury. Robbins v. United States, 624 F.2d 971 (10th Cir. 1980). Nor must the plaintiff know the cause of his or her injury in exhaustive detail. 28 U.S.C. § 2401(b) commences to run from the point at which the plaintiff's knowledge of his injury and its cause is sufficient to fairly justify placing the burden of inquiry upon him as to its legal consequences. The United States Court of Appeals for the Tenth Circuit steadfastly adheres to the principles of Kubrick, as will this Court in these proceedings. See Gustavson v. United States, _____ F.2d _____, No. 80-1420 (10th Cir. 1981).

Determining precisely what knowledge the hundreds of individual plaintiffs were "armed with" regarding the claims asserted herein, however, is not readily susceptible to wholesale a priori determination. The injuries alleged by the complaint herein are largely nonspecific as to cause. The fact that a plaintiff has discovered that he or she has contracted a form of leukemia, for example, does not without more lead a person to the conclusion that the Government has caused the disease through one means or another and that attorneys should

lic policy concerns to be "discretionary" within the meaning of 28 U.S.C. § 2680(a).[7]

Considered in light of the relevant case law as this Court has synthesized it to this point, the Government's motion to dismiss the complaint in the case now before it can be granted only if this Court is willing upon the present state of the record to determine that the Government's conduct in its entirety in carrying on the open-air nuclear testing at the Nevada Test Site was so fundamentally imbued with considerations of public policy as to be immunized from judicial scrutiny under the principles of separation of powers as embodied in the discretionary function exception to the Federal Tort Claims Act, 28 U.S.C. § 2680(a). The Government asks this Court to conclude at this point that the plaintiffs cannot prove any set of facts that would demonstrate wrongful or negligent conduct by any government employee involved in the testing program for which the United States would be liable, at least within the four corners of the plaintiffs' complaint.

Certainly a number of the decisions and judgments that went into the conduct of the atomic tests represented the exercise of discretion

---

[7] Other courts as well look to the policy content of a challenged governmental decision or action in determining its "discretionary" nature. In Relf v. United States, 433 F.Supp. 423 (D.D.C. 1977), for example, Judge Gasch of the District Court for the District of Columbia comments:

> As has been stated by the Supreme Court in Dalehite v. United States, the discretionary function exception is properly construed to include "determinations made by executives or administrators in establishing plans, specifications or schedules of operations. Where there is room for policy judgment and decision there is discretion." Id. . . . Although this construction has been narrowed somewhat by later cases, the exception unquestionably applies to decisions which of necessity involve the conscious balancing of policy considerations. J. H. Rutter Rex Manufacturing Co. v. United States, 515 F.2d 97, 99 (5th Cir. 1975); see Griffin v. United States, 500 F.2d 1059, 1064 (3rd Cir. 1974). See also Moyer v. Martin Marietta Corp., 481 F.2d 585, 597-98 (5th Cir. 1973). This would seem to be most particularly so with respect to those high-echelon decisions which by their very nature require the careful consideration of sensitive political and public policy factors.

Id., 433 F.Supp. at 427 (citations and footnote omitted). See also Green v. United States, 629 F.2d 581, 585 (9th Cir. 1980).

at the highest levels of government. It is fundmental that for those decisions, the United States is immune from tort liability.

But, one must understand that the words "discretionary function" as used in the Tort Claims Act, are really the correlative, the other side of the coin, of the exercise of executive power. The discretionary function exception merely reaffirms that courts should not interfere with executive decision making at the highest levels. Whether or not testing should be performed at all is obviously insulated from judicial interference. But, one must also recognize that discretion functioning at a presidential level, at a cabinet level or at an Atomic Energy Commission level is not the same thing at all as the exercise of judgment at a regional level, or at a site level, by a G.S. 16 manager, a scientist, an engineer, a public affairs or information officer, and auxiliary personnel.

While the word "discretion" may be spelled the same and sound the same, looking beyond the word, the function performed at each level of activity is a discretely different function.

Our job, of course, is to look beyond the words to the context in which a particular person may have been hurt and to determine if in that context the cost of that hurt to that person should be bourne alone by that person or shared by all for whose benefit the hurt may have been inflicted. Proceeding down the descending ladder of abstraction, from the general policy formulated on the highest level to the concrete implementation of that policy, one must understand that the case here is not footed on the fact that high level policy decisions were made—but is footed on the alleged, inappropriate manner in which such policy decisions were carried out. The distinction cries out.

As a conceptual device one may visualize the process as an inverted pyramid. The broad policy decision is at the top. As one descends, a multitude of judgments are made and functions and procedures performed in implementing the policy decision. Each such decision is quite obviously not the policy decision. Each is made at a different functional level and each is made in a different context and at a different time.

In short, when we speak of discretion we must focus on the specific level in the descending pyramid of decision making to see if, at that point, in that distinctive context of time and place and people, government actions are of such a nature that persons who are hurt through government actions at that level should in good conscience be made whole.

To re-iterate, discretion at one level may well be insulated and indeed should be. Judgment and related activity at a differing level may not be insulated and indeed should not be.

This Court cannot dismiss these cases wholesale at this stage of this proceeding upon the basis that each action up and down the ladder of governmental activity in conducting the testing program over a period of years was "discretionary," and thus insulated the government from answering in damages for alleged misconduct in carrying out the testing program. At this point we don't know enough. In a case of this magnitude fundamental fairness compels that any decision made be based on all available information. Thus, this Court now denies the Government's motion to dismiss based upon the discretionary function exception, 28 U.S.C. § 2680(a), without prejudice to its later reassertion upon a more complete record.

The United States urges that there be held what in effect would be a "mini-trial" upon the facts relevant to the dismissal motions. The justification for such a preliminary determination of the discretionary function issue is the fact that 28 U.S.C. § 2680(a)'s bar to tort suits is jurisdictional in nature. See Baird v. United States, _____ F.2d, _____, _____, No. 79-1441 (10th Cir. dec. June 29, 1981); First National Bank in Albuquerque v. United States, supra, 552 F.2d at 374. Because it is a jurisdictional issue, the Government properly expects that it will be determined first, in advance of any determination of the plaintiff's substantive claims. See Smith v. United States, 546 F.2d 872, 875-76 (10th Cir. 1976). This does not necessarily mean, however, that it be heard and considered wholly apart from and prior to a plenary hearing on the merits. As Judge Becker points out in Blessing v. United States, supra, "In the ordinary case, a jurisdictional issue is usually determinable on the face of

the pleadings or with a minimum of discovery." 447 F.Supp. at 1186.[8] Of course, this proceeding is far from the ordinary case.

Analytically, and as a practical matter, the discretionary function exception operates more as an affirmative defense than as a bar to jurisdiction. Blessing v. United States, supra. In a tort action, as the late Professor E. Wayne Thode instructs us,

> Whatever the kind of tort, and whatever the type of analysis, there are four basic issues that in some manner must be decided in plaintiff's favor in order for the plaintiff to obtain judgment. They are: (1) Is there a factual connection between plaintiff's injury and defendant? (2) Does the legal system's protection extend to the interest that plaintiff seeks to vindicate; and if some protection is afforded what standards of care does the legal system impose on the defendant? (3) Was that standard of care breached by the defendant? (4) What are the damages?

Thode, "Tort Analysis: Duty-Risk v. Proximate Cause and the Rational Allocation of Functions Between Judge and Jury," 1977 Utah Law Review 1 (1977). The discretionary function exception to the Federal Tort Claims Act logically falls within the second of the four issues to be determined, that dealing with the scope of the law's protection.[9] The discretionary function exception reflects the judgment of Congress that the scope of protection afforded by the tort

---

[8] The "jurisdictional facts" relevant to an action filed, for example, under 28 U.S.C. § 1332, the "diversity" jurisdiction statute, concern the relative diversity of state citizenship of the parties, a set of facts usually irrelevant to the factual basis of the controversy. While determining whether a federal district court possesses jurisdiction over a case brought under 28 U.S.C. § 1331, the "federal question" jurisdiction statute, is often more complex, cf. United Mine Workers v. Gibbs, 383 U.S. 715, 727 (1966), it is often based upon discernibly distinct elements within the parameters of the action.

[9] This issue in tort analysis is often characterized as the "duty" issue, i.e., whether the law imposes a duty upon the defendant to conform to a particular standard of conduct toward another, particularly the plaintiff. Prosser, Law of Torts 324 (4th ed. 1971).

law will not extend to persons injured by the conduct of employees and officers of the government which is clothed in the exercise of "discretion." Whatever the plaintiff's asserted interests are, be they economic, see Barton v. United States, 609 F.2d 977 (10th Cir. 1979), physical, see First National Bank in Albuquerque v. United States, 552 F.2d 370 (10th Cir. 1977), proprietary, see Spillway Marina, Inc. v. United States, 445 F.2d 876, 878 (10th Cir. 1971), or relational, see Colorado Insurance Group, Inc. v. United States, 216 F.Supp. 787, 792 (D.Colo. 1963), they are not entitled to legal protection against the defendant's "discretionary" conduct.

When treated as a substantive issue of tort analysis, this question of the scope of the law's protection is determined, as a general rule, upon the whole record following a trial in plenary fashion with full benefit of the discovery process and the honing effect of the pretrial conference. Why shouldn't the determination of the identical issue for jurisdictional purposes have the advantage of a complete record as a foundation? The analytical processes involved prove functionally the same. In determining whether the Government's conduct as challenged herein is "discretionary" within the meaning of § 2680(a), and whether the scope of the law's protection extends to the plaintiffs' interests herein, this Court must weigh administrative, economic, prophylactic and ethical factors similar to those considered in any negligence action. See L. Green, "The Duty Problem in Negligence Cases," 28 Columbia Law Review 1014, 1034 (1928); L. Green,

---

(CONT.)

> The question of liability for negligence cannot arise at all until it is established that the man who has been negligent owed some duty to the person who seeks to make him liable for his negligence. . . . A man is entitled to be as negligent as he pleases toward the whole world if he owes no duty to them.

Le Lievre v. Gould, [1893] 1 Q.B. 491, 497 (Lord Esher).

To say that the defendant owes a duty to the plaintiff is functionally a shorthand manner of stating the conclusion that the plaintiff's interests are entitled to legal protection as against conduct by the defendant that falls short of a legal standard. See Prosser, supra, at 325; L. Green, "The Duty Problem in Negligence Cases," 28 Columbia Law Review 1014 (1928). The discretionary function exception acts as a legislative yardstick for measuring the scope of the Government's duty to the public. Congress has said, in effect, that governmental officers who exercise "discretion" within § 2680(a) owe no duty of care to avoid negligent or wrongful injury to the interests of a universal class of plaintiffs.

"The Duty Problem in Negligence Cases: II," 29 Columbia Law Review 255 (1929). At most, the "jurisdictional" nature of the discretionary function exception would seem to require that this Court determine this issue first. This can, of course, be accomplished procedurally through the order in which this Court decides and announces each element of the causes of action. A finding in favor of the Government on the discretionary function issue [10] would obviate the necessity of making any further findings of fact or conclusions of law as to a specific claim. A "preferred order of proof" would seem neither needed nor helpful. Compare United States v. Stipe, _____ F.2d _____, No. 81-1417 (10th Cir. dec. July 1, 1981) (preferred order of proof in criminal conspiracy cases). The burden remains upon the plaintiffs to prove that the conduct of the defendant that allegedly resulted in the claimed injuries does not fall within the scope of the jurisdictional defense of § 2680(a), the discretionary function exception. See Baird v. United States, _____ F.2d _____, _____, No. 79-1197 (10th Cir. dec. June 29, 1981), slip op. at 8.[11]

In summary, this Court declines to further hear evidence or otherwise consider the applicability of the discretionary function exception to the proceedings at bar prior to full trial on the merits. The Federal Rules of Civil Procedure vest the courts with broad discretion to bifurcate, consolidate or otherwise coordinate issues and actions in litigation in the most effective manner. See Rule 42, F.R.Civ.P.; 5 Moore's Federal Practice ¶¶ 42.01 et seq. Where, as here, the jurisdictional issues are hopelessly inextricable from the facts to be proven under the substantive claims, denial of a separate trial of those issues is proper. Cf. Nordberg Mfg. Co. v. Barber-Greene Co., 47 F.R.D. 299, 300-301 (N.D.Ill. 1968). The Government does not deny

[10] The same may be said of the statute of limitations issue. See infra.

[11] The plaintiffs already bear the heavy burden of the first issue of tort analysis, the factual connection between plaintiffs' injuries and the defendant's conduct. Was the defendant's testing program the cause in fact of the plaintiffs' injuries? Two prior cases involving similar claims were resolved by determination of this first issue in favor of the Government. See Bartholomae v. United States, 253 F.2d 716 (9th Cir. 1958); Bulloch v. United States, 145 F.Supp. 824 (D. Utah 1956) (J. Christensen).

that this Court retains continuing power to determine its jurisdiction over the plaintiffs' claims, see United States v. United Mine Workers , 330 U.S. 258 (1947), a determination that this Court chooses to make upon a complete record. As Judge A. Sherman Christensen, now Senior District Judge for this District, commented in similar litigation more than 26 years ago,

> Within the perimeter of the pleadings I believe evidence could properly be received of acts in the scope of employment of agents of the Atomic Energy Commission which would not involve discretion or judgment and which, thus, would not be excluded either as a basis of liability under the Tort Claims Act or as a basis of individual liability. Whether such evidence is actually available is a point which is not before the Court. This evidence can be appraised at the proper time. Determinations as to the discretionary nature of specific acts or omissions may be difficult. Any mistakes in connection therewith may involve departures from the intent of Congress. If not corrected they may set patterns for similar departures. This can be best avoided in this case by hearing the evidence. But if the Government's position now were sustained on the pleadings, the [Federal Tort Claims] Act would be weakened, not by mere erosion, but by a virtual landslide which would remove from the buttress erected by Congress against governmental irresponsibility huge areas of activity in disregard of the real nature of the elements involved.

Bulloch v. United States, 133 F.Supp. 885, 892-893 (D.Utah 1955) (emphasis added).

As a brief comment preliminary to that trial, this Court notes that there is little if anything that appears now that would render the substance of the plaintiffs' claims unsuitable for resolution through the judicial process. The federal courts have dealt with radiation injury claims against the United States e.g., Kuhne v. United States, 267 F.Supp. 649 (E.D.Tenn. 1967); Annot., 73 A.L.R. 2d 1301 (1980), have resolved claims against the Government for allegedly negligent failure to warn persons of risks created by governmental conduct, see Indian Towing Co. v. United States, 350 U.S. 61 (1955); Smith v. United States, 546 F.2d 872 (10th Cir. 1976), United States v. White, 211 F.2d 79 (9th Cir. 1954), and have developed standards measuring

the scope of such a duty to warn, even as to radiation hazards. See e.g., High Voltage Engineering Corp. v. Pierce, 359 F.2d 33 (10th Cir. 1966). Judicially manageable standards have been applied to judge considerations of weather conditions, timing, etc., in reviewing the test-firing of sophisitcated devices such as rocket engines or similar devices. See e.g., Pigott v. United States, 451 F.2d 574 (5th Cir. 1971); H.L. Properties, Inc. v. Aerojet-General Corp., 331 F.Supp. 1006 (S.D.Fla. 1971). In fact, counsel for the Government has testified to Congress that the factual causation issues in litigation of this type, "while they are difficult and raise complex evidentiary issues, are not dissimilar from other scientific issues which may arise in litigation." Testimony of William Schaffer, in "Low-Level Radiation Effects on Health," Hearings, House Committee on Interstate and Foreign Commerce, 96th Cong., 1st Sess., Serial No. 96-129, at 241 (1979). The current Solicitor General of the United States, Rex Lee, testified that in his opinion, radiation cases "which arise out of the Nevada test bomb experience, can be handled under the existing provisions of the Federal Tort Claims Act, and, if they can, they should be." Id., at 238 (Testimony of Dean Rex Lee, Brigham Young University Law School).[12]

It is, therefore, readily apparent that, jurisdictional considerations permitting, a court could adequately adjudicate the plaintiffs' claims as borne out or defeated by the facts themselves.

II. THE STATUTE OF LIMITATIONS

Statutes of limitations, which "are found and approved in all systems of enlightened jurisprudence," Wood v. Carpenter, 101 U.S. 135,

---

[12] One approach suggested by Dean Lee to the tricky factual causation issues in this type of litigation was as follows:

> One is to say that inasmuch as Government caused some of the injury, and inasmuch as statistically the number caused by Government is considerably greater than those not caused by Government, then application of the traditional more probably than not test would indicate that the Government should be responsible for all, by analogy to the old Summers v. Tice case [199 P.2d 1 (Cal. 1948)].

Id., at 239. Under Dean Lee's formulation, "the burden ought to be shifted so that the Government must show that it, in fact, was not responsible for all." Id. (emphasis added).

be consulted as to the Government's potential liability. This is particularly true if, as plaintiffs have alleged, the Government has deliberately eschewed any cause-in-fact relationship between such injuries and its nuclear testing activities, and has consistently and with great authority made such denials for years.

The appropriate inquiry as to each plaintiff would seem to be whether more than two years prior to the filing of the plaintiff's claim the information known to, or reasonably imputed to the plaintiff was sufficient to put the plaintiff on notice that (1) he or she had been injured, and (2) that exposure to radioactive products of the Government's Nevada testing program is the cause of that injury to the reasonable exclusion of alternative causes. Where the information possessed by a plaintiff was sufficient to satisfy this dual inquiry, his or her claim is barred by 28 U.S.C. § 2401(b); where it was insufficient, the plaintiff may now proceed.

The Government urges that information provided through the mass media as to the effects of radioactive fallout from the Nevada testing program was substantive and pervasive enough to justify this Court in imputing sufficient knowledge as to cause to all of the plaintiffs per se. Extensive exhibits were provided detailing the coverage given by major newspapers, magazines, etc. during the testing program as well as subsequent to the cessation of open-air nuclear tests. However, just because a given piece of information is published in Time magazine on a particular date does not compel any court to charge a whole community, or the whole world, with knowledge of the contents thereof, or to conclusively presume that the information published is specifically accurate, or that it is presented in a form and manner calculated to inspire informed personal deliberation on the subject matter by its readers, or the general public. A review of the press coverage of the radioactive fallout controversy as submitted by both plaintiffs and the Government reveals statements that are alarming, statements that are reassuring, statements that are specific, statements that are vaguely ambiguous. The exhibits are contradictory, often unclear, and sometimes glaring with irony.[13] Beyond that, the Gov-

[13] Consider, for example, the statement by Dr. G. W. Beadle, then President of the American Association for the Advancement of Science, quoted in the Deseret News for May 17, 1955:

ernment does not seriously assert that each and every plaintiff herein had seen and read all of the coverage reflected in the exhibits, or even most of it.

This Court's own experience instructs it that people pay varying degrees of attention to events of public concern. Some individuals inform themselves in detail about relatively obscure matters, while others can remain nearly oblivious to news items that capture headlines for days. Each individual plaintiff, whether he or she has resided in Salt Lake City with its mass media network, or in Cedar City, or St. George, or Panguitch, or Hurricane, or Mount Carmel Junction, at the times relevant to this action, is lawfully entitled to an individualized determination of the statute of limitations issue as to his or her claim. That the plaintiffs herein are numerous should in no way be allowed to prejudice each individual's opportunity to seek a just adjudication of his or her claim. On this issue, fairness requires us to ask as to each litigant, "What did the plaintiffs know, and when did he or she know it?"

While the overall body of proof that the individualized determinations may require may appear unduly burdensome, I remind the parties that the injuries alleged in this case are hardly speculative or de minimis; they are indeed grave and have often proved fatal. Where people's lives are involved, extraordinary care should be given to the presentation and evaluation of all of the evidence.

> Dr. G. W. Beadle . . . said in a speech to the Medical Research Association of California Monday night that there was virtually no danger to individuals resulting from the minute increases in radiation from atomic tests.
>
> He said the danger of ill effects from radiation was "comparable to the danger of acquiring lung cancer from smoking cigarettes."

Id., at 5. Of course, we now know only too well the immense human and social costs accruing from the smoking of cigarettes and other tobacco products:

> [T]he hard facts [are] that cigarette smoking kills more than 320,000 Americans each year; 220,000 from heart disease, 78,000 from lung cancer, 22,000 from other cancer, and the rest from respiratory ailments such as chronic bronchitis and emphysema. I also emphasized the enormous public and private costs of smoking each year: $7 billion in health care, $18 billion in absenteeism, lost wages and lower productivity.

Joseph A. Califano, Jr., Governing America 185-186 (1981).

As with the discretionary function exception issue, this Court declines to accept the Government's suggestion that the statute of limitations issue be determined through the device of a preliminary "mini-trial" of the facts. Both the plaintiffs and the Government should have the benefit of an adjudication of the issues upon a complete record and this Court intends to proceed in that fashion. The limitations issue having been raised by the Government, the plaintiffs now bear the burden of proof as to the issue; they are in the better position to go forward in presenting the relevant evidence as to each plaintiff's knowledge under the Kubrick standard as part of their burden of establishing this Court's jurisdiction over their claims. See DeWitt v. United States, 593 F.2d 276, 281 (7th Cir. 1979); Lukenas v. Bryce's Mountain Resort, 538 F.2d 594, 597 (4th Cir. 1976); Mann v. United States, 399 F.2d 672 (9th Cir. 1972); Humphreys v. United States, 272 F.2d 411 (9th Cir. 1959).

III. THE MISREPRESENTATION EXCEPTION

At page 23, note 21, of its Motion to Dismiss for Lack of Jurisdiction (Discretionary Function), the Government asserts that the plaintiffs' claims that the United States is liable for giving false assurances as to the safety of exposure to radioactive fallout are barred by the "misrepresentation" exception to the Federal Tort Claims Act, 28 U.S.C. § 2680(h). Section 2680(h) excepts from the operation of the Act "[a]ny claim arising out of . . . misrepresentation, deceit," and other specific intentional torts.

It seems clear, however, that 28 U.S.C. § 2680(h) "protects the United States from liability in those many situations where a private individual relies to his economic detriment on the advice of a government official." Ramirez v. United States, 567 F.2d 854, 856 (9th Cir. 1977) (en banc). The exception reaches actions for misrepresentation or deceit in the classic sense, see W. Prosser, Law of Torts § 105 at 683 et seq. (4th ed. 1971), in which the plaintiff's asserted interest is pecuniary or economic. See Green v. United States, 629 F.2d 581, 584 (9th Cir. 1980). Where plaintiffs have asserted injuries to interests which are not pecuniary or commercial, courts have held that § 2680(h) does not preclude their claims. Indian Towing Co. v. United States, 350 U.S. 61 (1955); United States v. Neustadt, 366 U.S. 696,

711 n. 26 (1961); Ingham v. Eastern Airlines, Inc., 373 F.2d 227 (2d Cir. 1967), cert. denied, 389 U.S. 931; Betesh v. United States, 400 F.Supp. 238 (D.D.C. 1974). Where a plaintiff's physical well-being has been injured by, in part, false assurances given by the Government regarding the safety of its activities, the courts have readily found liability. See e.g., United States v. White, 211 F.2d 79, 81 (9th Cir. 1954).

The plaintiffs herein, insofar as they are pursuing claims for other than pecuniary, economic and commercial injuries, are not barred from proceeding by 28 U.S.C. § 2680(h).

IV. CONCLUSION

For the reasons stated herein above, the defendant's Motions to Dismiss for Lack of Subject Matter Jurisdiction pursuant to 28 U.S.C. §§ 2401(b) and 2680(a) are hereby DENIED without prejudice to their reassertion upon a more complete record. This litigation shall now proceed upon the timetable set by this Court.

DATED this 21 day of August, 1981.

BY THE COURT:

BRUCE S. JENKINS
United States District Judge

Copies mailed to counsel 8/21/81: mw
Dale Haralson, esq.
J. MacArthur Wright, Esq.
Stewart L. Udall, Esq.
Duncan, Weinberg, Palmer & Miller, P.C.
Wayne Owens, Esq.
Francis M. Wikstrom, U.S. Atty.
Ralph Johnson, AUSA

Stuart E. Schiffer, Esq.
Bruce E. Titus, Esq.
Pamela A. Hornett, Esq.
William R. Herman, Esq.
Deborah C. Ratner, Esq.
Henry A. Gill, Jr., Esq.
Alice Daniel, Esq.

Also mailed to counsel in C-81-0142J: mw
David L. Church, Esq.
Thomas Martin, Esq.
William Herman, Esq.
Ralph Johnson, AUSA

APPENDIX D

Judgment of the Tenth Circuit Court of Appeals

Filed, District Court of Utah, June 9, 1987

UNITED STATES COURT OF APPEALS
FOR THE TENTH CIRCUIT

MARCH TERM—APRIL 20, 1987.

Before the Honorable Monroe G. McKay, Honorable Oliver Seth and Honorable James K. Logan, Circuit Judges.

IRENE H. ALLEN, surviving spouse, WESLEY BEATTY HINTON, surviving child, heirs of M. VERNET HINTON, Deceased; ETHEL AVERETT, surviving spouse, ROSAMOND CANNON and ANNA A. FAULKNER, surviving children, heirs of JAMES FRANKLIN AVERETT, Deceased; VON J. BARNEY, surviving spouse, MACK LEE BARNEY, surviving child, heirs of MILDRED GRACE CRAPO BARNEY, Deceased; CLIFFORD S. BERG and GLENNA PICKETT BERG, surviving parents and heirs of MAILEEN BERG, Deceased; ANDREW J. BISTLINE and IRENE J. BISTLINE, surviving parents and heirs of ANDREW PAUL BISTLINE, JR., Deceased; KARL W. BRADSHAW, surviving spouse, LYNETTE BRADSHAW, LeANNE BRADSHAW and DAVID BRADSHAW, surviving children, heirs of SUSAN GREER BRADSHAW, Deceased; BERNICE C. BRINTON, surviving spouse and heir of WILDER HUFFAKER BRINTON, Deceased; LORNA C. BRUHN, surviving spouse, ELIZABETH ANN CATALAN and ELEANOR KAY McDONALD, surviving children, heirs of ARTHUR FREDERICK BRUHN, Deceased; FLORENCE M. CRABTREE, surviving spouse, JOHN ALBERT CRABTREE,

JUDGMENT
No. 84-2126
(D.C. No. C79-0515J)

GLENNA CRABTREE GIDDENS, WENDY LYNN C. SHIPE, PHYLISS B. C. GILLINS, JOYCE EMILY C. MESSER and CARROLL SMITH, surviving children, heirs of JOHN EDWARD CRABTREE, Deceased; DAVID ELMER DAVIES, Individually; SHARLENE GARDNER, surviving spouse, JUSTIN ELDRIDGE, JENENE ELDRIDGE, ELIZABETH ELDRIDGE, RONALD W. ELDRIDGE and CLINTON J. ELDRIDGE, surviving children and heirs of JOHN VACHEL ELDRIDGE, Deceased; GARTH JAY GILGER, NORMAN H. GILGER, WALLACE DARWIN GILGER, BARBARA JOY GRIMM and FREDA TALBOT, surviving children and heirs of HUGH GILGER, Deceased; HELEN F. HAFEN, surviving spouse, ANTHONY P. HAFEN, GLENN HAFEN and PAULINE H. NELSON surviving children, heirs of PAUL A. HAFEN, Deceased; LeORA HAFEN, surviving parent and heir of KARLENE HAFEN, Deceased; JULIA HALL, surviving parent and heir of RALPH DORAN HIGBEE, Deceased; MARGARET HARDY, surviving spouse and heir of HERBER V. HARDY, Deceased; JANICE L. HUMPHRIES, surviving spouse, CHRISTINA HUMPHRIES, MICHELLE HUMPHRIES and REBECCA HUMPHRIES, surviving children, heirs of RANDY HUMPHRIES, Deceased; BLAINE JOHNSON and LOA M. JOHNSON, surviving parents and heirs of SYBIL DESERET JOHNSON, Deceased; JANET MORTENSEN

JONES and MELVIN H. JONES,)
surviving parents and heirs of LUCILLE)
JONES, Deceased; ANNIE JUDD and)
OWEN JUDD, surviving parents and)
heirs of JANNELL JUDD, Deceased;)
MARTHA BARDOLI LAIRD, surviving)
parent and heir of MARTIN BARDOLI,)
Deceased; CLARK A. LAMOREAUX)
and WILMA LAMOREAUX, surviving)
parents and heirs of KENNETH D.)
LAMOREAUX, Deceased; CUBA H.)
LYLE, surviving spouse, LORRAINE)
LYLE WHITTAKER, MAXINE LYLE)
TERRANA and CALVIN H. LYLE,)
surviving children, heirs of LeROY)
WILLIAM LYLE, Deceased; JULIA M.)
BURCH LYNCH, surviving parent and)
heir of CAROL ODESSA BURCH,)
Deceased; ARTHUR MACKELPRANG)
and BESSIE A. MACKELPRANG,)
surviving parents and heirs of VANYARD)
DEWEY MACKELPRANG, Deceased;)
ROSE MARIE MACKELPRANG,)
surviving spouse, DALE)
MACKELPRANG, MARK)
MACKELPRANG, DIANA)
MACKELPRANG, LEE)
MACKELPRANG, VAN)
MACKELPRANG, SANDRA LARSEN)
and HAZEL M. HONEY, surviving)
children, heirs of GAYNELD JULIUS)
MACKELPRANG, Deceased; RUBY H.)
MATHESON, surviving spouse and heir)
of JOSEPH MICKELSON MATHESON,)
Deceased; VONDA Y. McKINNEY,)
surviving spouse, ARTHUR YOUNG)
McKINNEY, STEPHEN L. McKINNEY)
and DONNA LOU M. PATZKE,)
surviving children, heirs of LENN)
McKINNEY, Deceased; DORA B.)

McMULLIN, surviving spouse, KAYE)
CHRISTINA ADAMS, CLAIR B.)
McMULLIN and JACK LEON)
McMULLIN, surviving children, heirs of)
CLARENCE LEON McMULLIN,)
Deceased; KATHLEEN S. MILLETT)
and VERYL MILLETT, surviving parents)
and heirs of SHERRIE K. MILLETT,)
Deceased; ELMER O. MITCHELL,)
Individually; LEONORA T. MUIR,)
surviving spouse and heir of ERNEST)
ALFRED MUIR, Deceased; DARRELL)
A. NISSON, surviving parent and heir of)
SHELDON DARRELL NISSON,)
Deceased; RULA D. ORTON, surviving)
parent and heir of PEGGY LOUISE)
ORTON, Deceased; WILLIAM I.)
PALMER, surviving child and heir of)
KATE VILATE ISOM PALMER,)
Deceased; SUSIE PAYNE, Individually;)
ELMER S. PICKETT, surviving spouse,)
JEANNE P. COWAN, BRIAN LEE)
PICKET, KEVIN J. PICKETT and)
PAMELA PICKETT, surviving children,)
heirs of VIOLA MAE PICKETT,)
Deceased; LaRUE PRISBREY, surviving)
spouse and heir of HAROLD)
PRISBREY, Deceased; ARDELL)
ROBERTSON, surviving spouse,)
CONNIE JEAN ROBERTSON, a)
mentally incompetent person, HARMON)
F. ROBERTSON and CHARLENE R.)
MICKELSON, surviving children, heirs)
of FRANK HARMON ROBERTSON,)
Deceased; JAMES REECE SAMPSON,)
surviving spouse, MICHAEL R.)
SAMPSON and JAMES DON)
SAMPSON, surviving children, heirs of)
THEROL STEWART SAMPSON,)
Deceased; DON CARLOS SCHMUTZ,)

STANTON E. SCHMUTZ and MILTON DAVID SCHMUTZ, surviving children and heirs of AMBER TIMOTHY SCHMUTZ, Deceased; AFTON STAPLEY and ANNA SLACK, surviving children and heirs of GRETCHEN STOUT STRATTON, Deceased; WARD STRATTON and JACK BALLARD, surviving children and heirs of LOUIE BALLARD DeMILLE, Deceased; VeRENE E. TAIT, surviving spouse, LINDSEY C. TAIT, NAN TAIT, PATTI HEATON and TERESA T. BROOKSBY, surviving children, heirs of LaVIER C. TAIT, Deceased; STANLEY C. TURNER, surviving parent and heir of JEFFILYN TURNER, Deceased; RUSSELL M. WILSON, Personal Representative of the Estate of ELDAN LeROY PORTER, Deceased; CLEO ADAMS, surviving spouse and heir of ALMA ALEXANDER GREN, Deceased; DANIEL BARLOW and LORAN LUCILLE BARLOW, surviving parents and heirs of HYRUM DANIEL BARLOW, Deceased; EMMA JEAN BESS, surviving spouse and heir of JEWELL KENT BESS, Deceased; JEFFREY W. BRADSHAW, Individually; VALDA FREI, surviving spouse, ROBERT FREI and LEAH BRACKEN, surviving children, heirs of CLAWSON FREI, Deceased; BEVERLY LARSON HALL, surviving child and heir of RUBIN LARSON, Deceased; GORDON W. HANSEN, surviving parent and heir of BILL DANA HANSEN, Deceased; GRAYCE RUTH HARDY, Individually; KENT HOYT and MARTHA L. HOYT, surviving parent and heirs of DARWIN J.

HOYT, Deceased; PATRICIA LOUISE)
KIRK, Individually; BOYD C.)
PAULSON, JR., Individually; BETTY L.)
ADAMS, Individually; FRANK)
ADAMS, Individually; MRS. KENNETH)
(IRIS) ADAMS, Individually; JAMES)
M. AMEND, Individually; CLARENCE)
A. ANDERSON, Individually; BLAINE)
R. ANDRUS, Individually; LOUIS)
DALE ARNOLD, Individually; LOUIS)
C. BALSLY, Individually; LOUIS C.)
BALZLY and MAUREEN RAMSAY,)
surviving children and heirs of ISABELL)
FILER CROFT, Deceased; AGATHA)
BARNUM, Individually; ISADORE)
BARTON, Individually; MELVA)
BARTON, Individually; NANCY C.)
BASSETT, Individually; BEULAH S.)
BEAUMONT, Individually; CHESTER J.)
BEHRING, surviving spouse and heir of)
GRACE MARIE BEHRING, Deceased;)
CURTIS M. BERRY, RUSSELL BERRY,)
CHAROLETTE BERRY, GLEAVE and)
CRAIG BERRY, surviving children and)
heirs of DONNA JEAN BERRY,)
Deceased; CLEO ALGER BESS,)
Individually; BETTY VERDEAN)
BINIAZ, Individually; KATHERINE D.)
BLACKHAM, Individually; DENZIL)
BLAKE, Individually; LOIS BRYANT)
BLOOD, surviving spouse, LOGAN)
STEVENS BRYANT, ENID LaREE)
CLARK, MYRLE SCHULE, ENEAL)
ERROR and CAROLYN PECTOL,)
surviving children, heirs of NAVE)
EDGAR BRYANT, Deceased; JUNE)
CAROL BOND, Individually; LILLIAN)
S. BOSSHARDT, Individually;)
MILDRED B. BOWLER, surviving)
spouse and heir of WILLARD LEWIS)

BOWLER, Deceased; FLORA T.)
BOWMAN, Individually; MAREL)
BRADSHAW, surviving spouse,)
GERALD W. BRADSHAW, surviving)
child, heirs of DELSA WINDSOR)
BRADSHAW, Deceased; SHERWIN)
BRADSHAW, surviving spouse and heir)
of MARIE WOOD BRADSHAW,)
Deceased; VERLYNN W. BRADSHAW,)
Individually; VINA R. BRINGHURST,)
Individually; DONNA RAE)
BROHAMER, Individually; EARL)
BUNN, Individually; ELIZABETH)
BURGESS, Individually and as surviving)
child and heir of MABLE LEE,)
Deceased; MARY CATHERINE)
BURRELL, surviving child and heir of)
MARTIN NIELSON and LILLIAN)
GRACE NIELSON, Deceaseds;)
DONALD E. BURTON, EDWARD A.)
BURTON and FRANKIE LOU)
BENTLEY, surviving children and heirs)
of ALBERTA W. DALTON, Deceased;)
NORMA S. BURTON, surviving spouse,)
DAVID M. BURTON, REX D. BURTON)
and CHARLENE B. ANKER, surviving)
children, heirs of CHARLES)
FRANKLIN BURTON, Deceased;)
DWIGHT L. CARTER, surviving spouse)
and heir of MARGARET MAY)
CARTER, Deceased; MARY ALICE)
CARTER and CATHERINE COTTOM)
STUCKI, surviving children and heirs of)
RUTH SHEPHERD COTTOM,)
Deceased; LEOLA CHATTERLEY,)
surviving spouse, THOIS)
CHATTERLEY, RICHARD GRAYDON)
CHATTERLEY, CHRISTINA C.)
CARLSON and SHANNA LUE C.)
McGUIRE, surviving children, heirs of)

JOSEPH GRAYDON CHATTERLEY,)
Deceased; TANYA W. CHRISTIAN,)
Individually; MARIUS CLOWARD,)
Individually; FANNIE I. COBB,)
surviving spouse and heir of CHARLES)
A. COBB, Deceased; DIANE)
NISSON COFFEY, Individually;)
GLENNA W. COOPER, Individually;)
MILO CORRY, Individually; ELSIE B.)
COX, Individually; EMILY COX,)
Individually; THORLEY JIM COX,)
Individually; MARY G. CROSBY,)
surviving spouse and heir of RAWLAN)
CHATTERLEY CROSBY, Deceased;)
HOPE DALTON, Individually; LaRUE)
H. DANNELLY, Individually; HAZEL B.)
DAVIES, surviving spouse, DAVID B.)
DAVIES, surviving child, heirs of IVAN)
JOSIAH DAVIES, Deceased; JAMES S.)
DEAN, surviving child and heir of)
ROBERT ALEXANDER DEAN,)
Deceased; ANGELINE B. DEDMAN,)
Executor of the Estate of RUTH)
DRANEY, Deceased; VELVA EARLEY,)
Individually; LOUISE H. EGAN,)
Individually; MATA G. ENCE, surviving)
spouse, FLOYD ENCE, LILLIS E.)
SPENCER and PAULINE E. OLDS,)
surviving children, heirs of ERNEST)
RUEBEN ENCE, Deceased; RAY)
ENGLESTEAD, Individually; LUCILLE)
EVANS and SAM EVANS, surviving)
parents and heirs of AFTON EVANS,)
Deceased; LYNN EVANS, Individually;)
MARY CATHERINE FORD,)
Individually; HILDA F. GARDNER,)
Individually; J. RONALD GARN,)
Individually and as surviving spouse and)
heir of ANNETTA MOFFITT GARN,)
Deceased; RONALD GARNER and)

BETTY GARNER, surviving parents and)
heirs of MICHELE GARNER, Deceased;)
MARVIA N. GOODWIN, surviving)
spouse and heir of CHARLES EDWARD)
GOODWIN, Deceased; PAULINE H.)
GOUDIE, Individually; KENNETH)
GOWER, Individually; LeORA HAFEN,)
surviving spouse, H. JOHN HAFEN and)
KIM HAFEN, surviving children, heirs of)
KARL WILLIAM HAFEN, Deceased;)
LeORA HAFEN, Individually;)
CLAUDIA J. HALTERMAN and C.)
TIBBS ADAMS, surviving children and)
heirs of CLAUDE WHITNEY ADAMS,)
Deceased; MARION P. HALTERMAN,)
surviving spouse, ROBERT L.)
HALTERMAN, KENNETH)
HALTERMAN and DONALD M.)
HALTERMAN, surviving children, heirs)
of VERIAN LOWDER HALTERMAN,)
Deceased; LAMAR HAMBLIN,)
Individually; BARBARA E. HAMBLIN,)
surviving spouse, HAROLD E.)
HAMBLIN, KAREN H. KELLY and)
JAN HAMBLIN LEAVITT, surviving)
HAMBLIN LEAVITT, surviving)
children, heirs of METZ TURNER)
HAMLIN, Deceased; DELMA H.)
HAMMER, Individually; MAUREEN B.)
HAMMON, Individually; GRANT B.)
HARRIS, Individually; ALMA)
HARTLAND, surviving spouse and heir)
of RAYMOND A. FALLINI, Deceased;)
CAROLINE S. HATCH, surviving spouse)
and heir of KERMIT STEVEN HATCH,)
Deceased; ANN COX HAWKES,)
Individually; ANN COX HAWKES,)
surviving spouse, CAROLEE COX)
HALL, SALLY COX OSNESS and LEE)
WARREN COX, surviving children, heirs)

of LEE WARREN COX, Deceased;)
STEVE M. HEATON, surviving child and)
heir of CLIFFORD K. HEATON,)
Deceased; FAYE P. HOLLINGSHEAD,)
surviving spouse, CAROLYN)
HOLLINGSHEAD, SCOTT R.)
HOLLINGSHEAD and SANDRA H.)
CHRISTIANSEN, surviving children;)
heirs of JACK ROBINSON)
HOLLINGSHEAD, Deceased; MARY E.)
HOLLINGSWORTH, surviving spouse,)
WESLEY STEVEN HOLLINGS-)
WORTH, surviving child, heirs of)
VERNON HOLLINGSWORTH,)
Deceased; CLAUDE HULET,)
Individually; ISABELLA N. HULET,)
Individually; BARBARA S. HUNT,)
Individually; LINDIA AMELIA HUNT,)
surviving spouse and heir of NEPHI)
HUNT, Deceased; SARAH C. HUNTER,)
surviving spouse, SINDY LAURA)
HUNTER, ROY CLINTON HUNTER,)
surviving children, heirs of GEORGE)
CLINTON HUNTER, Deceased;)
FRANCES KATHLEEN HYDE,)
Individually; GOLDA IVERSON,)
surviving spouse, LEON B. IVERSON,)
surviving child, heirs of ALVIN)
MERINUS IVERSON, Deceased; INA)
M. IVERSON, Individually; FLORENCE)
JOLLEY, Individually; MARY W. HALL)
JONES, surviving spouse, LARON W.)
HALL, ARLENE HALL CAMPBELL,)
CLAYTON HALL, CLAIR W. HALL,)
CONNA HALL, LYNN JOSEPH HALL,)
WENDY PATRICIA HALL, surviving)
children heirs of WENDELL PICKETT)
HALL, Deceased, ALBERTA EVANS)
KARTCHNER, Individually; NORLEAN)
KELLY, Individually; MILES H.)

KLEINMAN, Individually; ESTER)
ADAIR LAUB, surviving spouse, GREG)
ADAIR, DALLAS ADAIR, LaVOY)
ADAIR and SHARON WEISS, surviving)
children, heirs of ARNOLD ANDREW)
ADAIR, Deceased; DUANE W. LEARY,)
surviving parent and heir of TAMERA)
LYNN LEARY, Deceased; LOUISE W.)
LESSING, surviving spouse and heir of)
LeROY MYRON LESSING, Deceased;)
ROENA LEE, Individually; LaPRIEL E.)
LIMEFORD, surviving child and heir of)
ELLEN MARIA ENGELSTAD,)
Deceased; LEONA C. LYMAN,)
Individually; MARY W. LYMAN,)
Individually and as surviving spouse and)
heir of RULON LYMAN, Deceased;)
ROY E. LYTLE, surviving spouse,)
GORDON R. LYTLE, KENNETH E.)
LYTLE and LaRUE WALKER, surviving)
children, heirs of EDITH EMPEY)
LYTLE, Deceased; SHERON H.)
MADSEN, Individually; BEVERLY W.)
MANGUM, Individually; MARIE C.)
MANGUM and BARBARA AVERY,)
surviving children and heirs of ADRELL)
HUNT CARTER, Deceased; AGATHA)
MANNERING, Individually; CHARLES)
MANNERING, Individually; LAURA)
DIANE MARTIN, Individually;)
MILDRED MAXWELL, surviving)
spouse, CLARK V. MAXWELL, GAIL)
O. MAXWELL, GERALD L.)
MAXWELL, KARLENE MAXWELL,)
KEITH L. MAXWELL, LEON K.)
MAXWELL, MARLENE MAXWELL)
and MAX LOUIS MAXWELL,)
surviving children, heirs of LOUIS)
CLOW MAXWELL, Deceased;)
ERNEST JAMES MAY, surviving spouse,)

ROBIN MAY, LANNY TODD MAY,)
WENDY MAY ADAMS and JODY)
MAY, surviving children, heirs of)
COLLEEN SIMMONS MAY, Deceased;)
IRENE H. McEWEN, Individually;)
ERMA L. McINTOSH, surviving spouse,)
JOSEPH MARION COX, surviving)
child, heirs of ROLAND ELI COX,)
Deceased; ERMA L. McINROAH,)
surviving parent and heir of RODNEY)
ELDON COX, Deceased; MELVIN H.)
MILES, Individually; VERA MURPHY,)
surviving parent and heir of DOUGLAS)
ALAN MURPHY, Deceased;)
GERTRUDE NELSON, surviving spouse)
and heir of LELAND MARK NELSON,)
Deceased; ISAAC ARTHUR NELSON,)
surviving spouse and heir of OLETA)
BETTRIDGE NELSON, Deceased;)
PETER A. NELSON, surviving parent)
and heir of FRAZER T. NELSON,)
Deceased; STELLA LEE NELSON,)
Individually; PAMELA K. OLSEN,)
Individually; ESTELLE F. ORTON,)
Individually; GLENNA H. ORTON,)
surviving child and heir of GLEN)
SCOTT HOLYOAK and GRACE)
MATHESON HOLYOAK, Deceaseds; H.)
FRANK ORTON, Individually;)
JUANITA W. ORTON, surviving spouse,)
NINA ORTON, WYLEE WEST ORTON)
and YVONNE ORTON, surviving)
children, heirs of MELVIN OSCAR)
ORTON, Deceased, ARVILLA A.)
OUTSEN, Individually; MELBA)
PARKER, Individually; EMMA PEACE,)
surviving spouse and heir of JAMES T.)
PEACE, Deceased; DWIGHT PECTOL,)
surviving spouse and heir of LISA D.)
PECTOL, Deceased; BESSIE G.)

PERKINS, Individually; DEAN J.)
PIERSON, Individually; NORMA JEAN)
POLLITT, Individually; DENISE)
PRINCE and JAMES N. PRINCE,)
surviving children and heirs of DAISY)
LOU PRINCE, Deceased; ELAINE)
PRISBREY and SCOTT PRISBREY,)
surviving parents and heirs of CHAD K.)
PRISBREY, Deceased; J. COLEMAN)
PRITCHETT, Individually; ANTONE B.)
PRYOR, surviving child and heir of)
EDITH SUE PRYOR, Deceased;)
MORRIS RASMUSSEN, Individually;)
MRS WALTER RAY, Individually;)
SHERI LEE REBER, Individually; AMY)
LINDER REESE, Individually; AMY)
LINDER REESE, surviving spouse,)
JOSEPH N. REESE and KENLEY)
LINDER REESE, surviving children,)
heirs of JOSEPH HYRUM REESE,)
Deceased; ERNEST CLINTON)
ROBINSON, HUGH ROBINSON,)
ERMA LAMOREAUX and RUBY R.)
BAUER, surviving children and heirs of)
SARAH LYDIA ROBINSON, De-)
ceased; IDELLA D. ROBINSON,)
Individually; DOUGLAS C. ROGERS, G.)
BRUCE ROGERS and JOHN M.)
ROGERS, surviving children and heirs of)
GWENDOLYN BUSHMAN ROGERS,)
Deceased; JETTA DECKER ROWLEY)
and RICHARD E. ROWLEY, surviving)
parents and heirs of JETTA DECKER)
ROWLEY, Deceased; DELWORTH)
RUESCH, surviving spouse, MALLORY)
RUESCH, RANDY RUESCH, SHERRIE)
RUESCH ROSE and DIANE RUESCH)
DEWEY, surviving children, heirs of)
LORRAINE S. RUESCH, Deceased;)
MELVA RUESCH, Individually;)

JACQUELINE M. SANDERS,)
Individually; MARGARET SANDERS,)
surviving spouse and heir of BERL)
SANDERS, Deceased; NORMA S.)
SANDERS, surviving spouse and heir of)
CECIL WILLIAM SANDERS,)
Deceased; DON CARLOS SCHMUTZ,)
Individually; SHIRLEY B.)
SEEGMILLER, Individually;)
WENDELL SEEGMILLER,)
Individually; RETHA W. SHURTZ,)
Individually; JOSEPHINE SIMKINS,)
surviving spouse, RENEE SIMKINS,)
CHRISTINE S. BOWLER and JAMES)
L. SIMKINS, surviving children, heirs of)
JUNE WINSOR SIMKINS, Deceased;)
NINA S. SMIRL, Surviving spouse and)
heir of W. J. SMIRL, Deceased; AFTON)
H. SMITH, surviving spouse and heir of)
DONALD DUFFIN SMITH, Deceased;)
DENNIS K. SMITH, Individually; FRED)
B. SMITH, Individually; PENN HARRIS)
SMITH, surviving child and heir of)
ELIAS PENN SMITH and LOUIE)
HARRIS SMITH, Deceaseds; GRACE)
E. SNOW, Individually; LENORA B.)
SPENDLOVE, surviving spouse and heir)
of KARL E. SPENDLOVE, Deceased;)
HEBER R. STAHELI, surviving spouse,)
LAURENCE H. STAHELI, VALERIE)
STAHELI, DELANIE STAHELI and)
SHERRI S. REBER, surviving children,)
heirs of ARDATH ESPLIN STAHELI,)
Deceased; MELISSA BEAMES)
STANDWORTH, surviving spouse and)
heir of BLUEFORD T. STANDWORTH,)
Deceased; A. LAMAR STOKER,)
surviving spouse and heir of EDNA)
BETH TALBOT STOKER, Deceased;)
MRS. NOLAN STOKES, surviving)

spouse and heir of JAMES NOLAN)
STOKES, Deceased; DANIEL MARLO)
STONES, surviving parent and heir of)
BRUCE MARLO STONES, Deceased;)
LILLIAN S. STRATTON, Individually;)
EMERALD WAYNE STUCKI,)
Individually; PATRICIA SWANSON,)
surviving parent and heir of TAMERA)
LYNN LEARY, Deceased; ANNA B.)
TAYLOR, Individually; AMY TERRIL,)
Individually; AMY TERRIL,)
Individually; BONNIE THAYER,)
Individually; JUNE D. THOMPSON,)
Individually; S. HAROLD THOMPSON,)
Individually; S. HAROLD THOMPSON,)
Individually and as surviving spouse and)
heir of GERALDINE THOMPSON,)
Deceased; TWILA B. THORTON,)
Individually; IVAN V. TOPHAM,)
surviving child and heir of JOSEPH)
ERNEST TOPHAM, Deceased; EDNA)
TRIMBLE Individually and as surviving)
spouse and heir of JOHN ARCHIE)
TRIMBLE, Deceased; GERN D. URIE,)
Individually; LIONELL A. WALKER,)
Individually; PATRICIA G. WALTER,)
Individually; ESTHER G. WARD,)
surviving spouse and heir of)
FREDERICK JARVIS WARD,)
Deceased; H. L. WASDEN, Individually;)
JOAN W. WASDEN, surviving spouse)
and heir of NEWEL F. WASDEN,)
Deceased; JOAN W. WASDEN, surviving)
child and heir of JOSEPH EDWARD)
WARD, Deceased; HELENA B.)
WATSON, Individually and as surviving)
spouse and heir of ODELL JOHNSON)
WATSON, Deceased; ELEANOR KEIL)
WEBB, Individually; VILATE L. WEBB,)
surviving spouse, RALPH L. WEBB,)

EVELYN W. JONES and MARY WEBB JONES, surviving children, heirs of ARVEL THOMPSON WEBB, Deceased; MRS. KENT WHIPPLE, surviving spouse and heir of KENT O'NEIL WHIPPLE, Deceased; OPAL WHITLOCK, surviving spouse and heir of ARTHUR BOYCE WHITLOCK, Deceased; LUKE LORIN WILCOCK, Individually; ROSCOE H. WILKES, surviving spouse and heir of ALBERTA MAY WILKES, Deceased; JOSEPH F. WILLIAMS, Individually; DELWIN L. WILSON, surviving child and heir of ERMA LOUISA NELSON WILSON, Deceased; PAUL W. WOOD, surviving spouse and heir of CATHERINE BADGER WOOD, Deceased; LAURA SNOW WOODBURY, surviving spouse and heir of DAVID ORIN WOODBURY, Deceased; JANICE L. WOODS, Individually; ZINA B. WOOLSEY, Individually,

Plaintiffs-Appelles,

vs.

UNITED STATES OF AMERICA,

Defendant-Appellant.

This cause came on to be heard on the record on appeal from the United States District Court for the District of Utah, and was argued by counsel.

Upon consideration whereof, it is ordered that the judgment of that court is reversed with regard to those nine claims in which the government was found to have liability. The cause is remanded to the United States District Court for the District of Utah for further proceedings consistent with this opinion.

(ORIGINAL SIGNED)

ROBERT L. HOECKER
Clerk

APPENDIX E

EXCERPTS FROM THE ATOMIC ENERGY ACT OF 1946

Sec. 3.(a) Research Assistants--The Commission is directed to exercise its power in such manner as to insure the continued conduct of research and development activities in the fields specified below by private or public institutions or persons and to assist in the acquisition of an ever-expanding fund of theoretical and practical knowledge in such fields. To this end the Commission is authorized and directed to make arrangements (including contracts, agreements, and loans) for the conduct of research and development activities relating to--

(1) nuclear processes;

(2) the theory and production of atomic energy, including processes, materials, and devices related to such production;

(3) utilization of fissionable and radioactive materials for medical, biological, health, or military purposes;

(4) utilization of fissionable and radioactive materials and

processes entailed in the production of such materials for all other purposes, including industrial uses; and

(5) the protection of health during research and production activities.

The Commission may make such arrangements without regard to the provisions of sec. 3709 of the Revised Statutes (U.S.C., title 41, sec. 5) upon certification by the Commission that such action is necessary in the interest of the common defense and security, or upon a showing that advertising is not reasonably practicable, and may make partial and advance payments under such arrangements, and may make available for use in connection therewith such of its equipment and facilities as it may deem desirable. Such arrangements shall contain such provisions to protect health, to minimize danger from explosion and other hazards to life or property, and to require the reporting and to permit the inspection of work performed thereunder, as the

Commission may determine; but shall not contain any provisions or conditions which prevent the dissemination of scientific or technical information, except to the extent such dissemination is prohibited by law.

Sec. 4.(c)(2) Operation of the commission's production facilities--The Commission is authorized and directed to produce or to provide for the production of fissionable material in its own facilities. To the extent deemed necessary, the Commission is authorized to make, or to continue in effect, contracts with persons obligating them to produce fissionable material in facilities owned by the Commission. The Commission is also authorized to enter into research and development contracts authorizing the contractor to produce fissionable material in facilities owned by the Commission to the extent that the production of such